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ABSTRACT

The International Council of Scientific Unions formed the Scientific Committee on Problems of the Environment (SCOPE) to survey environmental changes, recommend international research programes, and suggest ways and means of lessening environmental hazards. In this publication, an attempt is made to identify to college students and interested professionals throughout the world those environmental issues and problems presently facing us or looming in the future. This publication not only closely examines environmental issues and problems but also inspects our research and problem solving approaches to these problems and the responsibilities of the scientific community. Just a few of the topics examined in this publication are environmental properties and processes; the role of science in environmental policy; biogeochemical cycles; pollutants in the environment; problem identification and monitoring; standard setting; and future actions. (MR)

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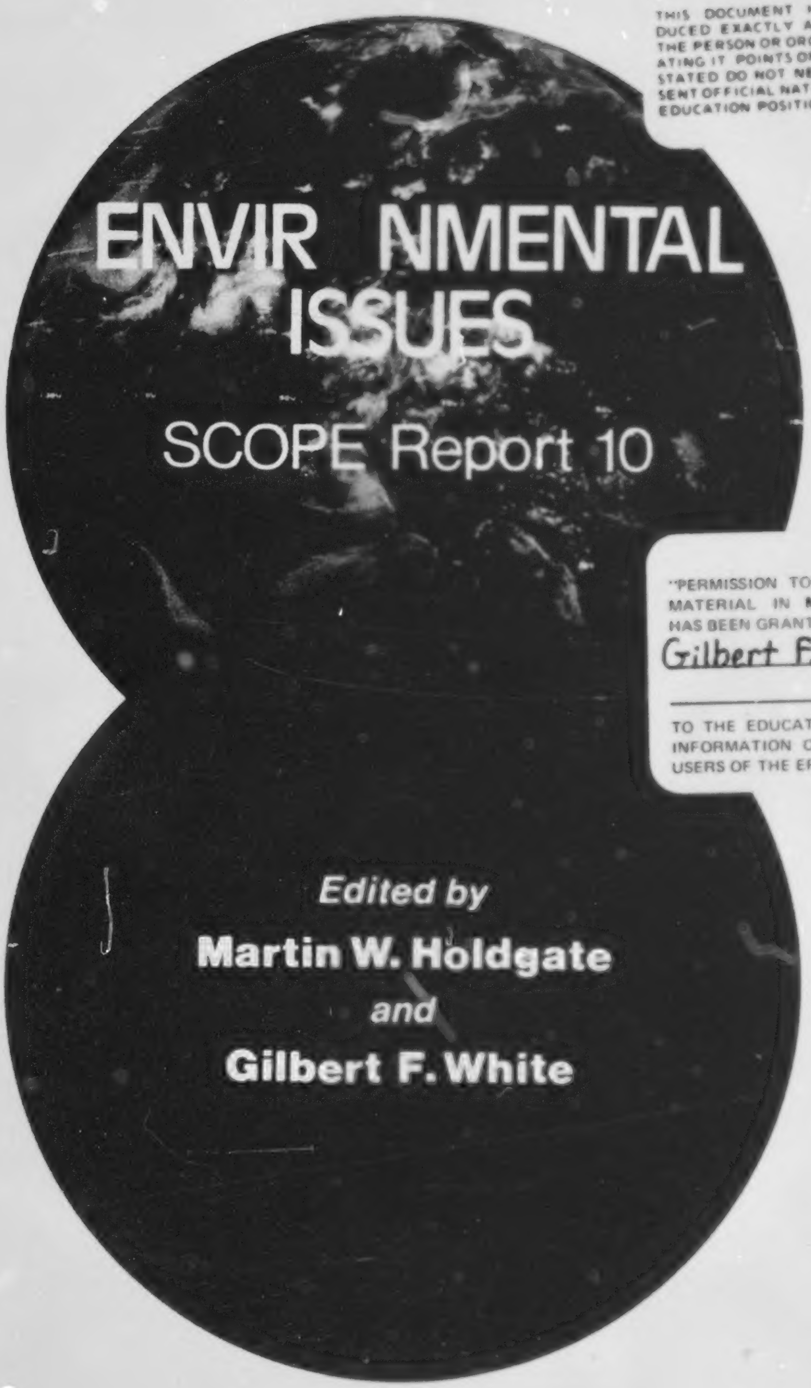

ENVIRONMENTAL ISSUES

SCOPE Report 10

Edited by

Martin W. Holdgate

and

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Scientific Committee on Problems of the Environment (SCOPE)

ICSU is an international non-governmental scientific organization comprising eighteen Scientific Unions, which span the whole range of natural sciences, and 65 National Members. To cover multidisciplinary activities which include the interests of several unions, ICSU has established a number of scientific committees, of which SCOPE, founded in 1969, is one. Currently, representatives of 32 member countries and 15 Unions and Scientific Committees participate in the work of SCOPE, which directs particular attention to the needs of developing countries.

The mandate of SCOPE is to assemble, review, and assess the information available on man-made environmental changes and the effects of these changes on man; to assess and evaluate the methodologies of measurement of environmental parameters; to provide an intelligence service on current research; and by the recruitment of the best available scientific information and constructive thinking to establish itself as a corpus of informed advice for the benefit of centres of fundamental research and of organizations and agencies operationally engaged in studies of the environment.

SCOPE is governed by a General Assembly, which meets every three years. Between such meetings its activities are directed by the Executive Committee.

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Environmental Issues

SCOPE REPORT 10

Report by SCOPE to the ICSU General Assembly, October 1976

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Environmental Issues

SCOPE REPORT 10

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Foreword

From the time that human beings first appeared upon the earth they have affected the environments in which they have lived. As time passed, as their technologies expanded to include agriculture and metallurgy, and as human population grew and spread to all continents, environmental changes brought about by human activity accelerated. Large continental areas were deforested, mountains were covered by terraces, rivers were diverted to make deserts bloom. Such changes, although profound, nevertheless were brought about very slowly when compared with the life expectancy of an individual. For the most part humans died in environments which were much the same as those in which they had been born.

As the pace of technological change quickened, so did the pace of environmental change. Today we see dramatic changes taking place virtually everywhere on earth – on the land, in the oceans, and in the atmosphere. All people in all parts of the world are being affected in varying degrees by environmental changes which are being caused by human activity.

The International Council of Scientific Unions was one of the first major international bodies of scientists to recognize that a number of the environmental changes which are taking place could well be confronting humanity with unprecedented dangers. After much discussion the decision was made to create the Scientific Committee on Problems of the Environment (SCOPE). The new Committee was charged with the obligation of surveying environmental changes which are taking place, of making recommendations for international research programmes aimed at better understanding those changes, and of suggesting ways and means of lessening environmental hazards to human beings everywhere.

SCOPE has done its work well. The cadres of scientists from all parts of the world who have volunteered for this effort have given generously of their time, energy, and wisdom in order to produce this major report. I had the good fortune of playing a role in the creation of SCOPE so it was with some feeling of pride that I found myself President of ICSU during the final two years of this effort.

I know that the past and present officers of both SCOPE and ICSU join me in the hope that this report will be read and acted upon by people in all parts of the world and that in some measure it will contribute to a better understanding of some of these serious problems which confront us all.

Harrison Brown
President of ICSU, 1974–1976

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Preface

The General Assembly of the International Council of Scientific Unions (ICSU) directed its Scientific Committee on Problems of the Environment (SCOPE) to report to ICSU in October 1976, on global trends in the biosphere and environmental issues most urgently requiring international and interdisciplinary scientific effort. SCOPE was asked to indicate how far there was agreement, differences of judgment, and a need for further scientific research on these subjects. The Bureau of SCOPE entrusted the preparation of its report to a Steering Committee in collaboration with the officers.

The present Report comes at the end of two phases in the history of the Scientific Committee. During the first, formative phase, SCOPE played an active part, on behalf of ICSU, in providing scientific statements to the Secretariat preparing the United Nations Conference on the Human Environment, held at Stockholm in June 1972. SCOPE prepared a report that formed the basic working document for an Intergovernmental Working Group on Monitoring and put forward proposals for an International Registry of Toxic Chemicals, in both instances influencing the development of themes that now form part of the action programme of the United Nations Environment Programme. The second phase in the history of SCOPE, overlapping with the first and in many ways exceeding it in importance, has been the development and operation of the Mid-term Programme. The activities of SCOPE have been conducted in close liaison with a number of other members of the ICSU family; many elements in SCOPE's programme, for example, have built upon and developed work begun under the Special Committee for the International Biological Programme (SCIBP) which organized the World Programme on 'Biological Productivity and Human Welfare' from 1964 to 1974.

In compiling the Report, the authors were guided by the long-term objectives of SCOPE:

–Advancing knowledge of the influence of human activities upon the environment and the effects of the resulting changes on human health and welfare, with particular attention to those influences which are global or common to several nations; and

–Serving as a non-governmental, interdisciplinary source of objective advice for the benefit of governments and intergovernmental agencies with respect to environmental questions of wider purview than those of individual Unions and Committees of ICSU.

The Report addresses itself to three specific questions concerning selected aspects of the global environment:

(a) what changes have been recognized by environmental scientists?

(b) what other changes have been postulated but remain controversial, and should be regarded as issues for analysis rather than as certainties?

(c) what changes may possibly be taking place, but cannot be regarded even as postulates without further evaluation?

The first part of this Report (Chapters 1 and 2) examines static and dynamic elements in the biosphere and considers their impact on the human situation today. Chapter 2 is especially concerned with the development of means for the more rigorous recognition, analysis, and evaluation of environmental changes and their effects. Both chapters provide a general philosophical preface to the second part (Chapters 3, 4, and 5) which summarizes progress in the seven projects of the Mid-term Programme of SCOPE and the related work by other ICSU Unions and Committees. The seven projects of the Mid-term Programme are concerned with:

I. Biogeochemical cycles;
II. Human impact on renewable natural resources;
III. Environmental aspects of human settlement;
IV. Ecotoxicology;
V. Simulation modelling;
VI. Environmental monitoring; and
VII. Communication of environmental information and societal assessment and response.

Finally, Chapter 6, which forms the third part of the Report, takes a forward look at ICSU's opportunities in the environmental field and at how SCOPE's work might develop after the completion of the Mid-term Programme.

The report is addressed in the first place to ICSU, as formality requires. Through ICSU, it can reach a substantial part of the world's scientific community, in and through scientific unions and national academies.

Detailed accounts of the Mid-term Programme projects will be published as they reach a conclusion. Such accounts, other documents of the Scientific Unions, and this report have the objective of helping scientists and those who support them to decide what research, on what problems, is pertinent to solving current and forecast environmental problems.

One widely held conclusion for which this report provides support is that it is of crucial importance that information flows freely amongst the scientific disciplines. Environmental problems are almost always multidisciplinary in nature. They demand an integration of biological, physical, chemical, and behavioural skills for their solution. Nationally and internationally, the efficient harnessing of a wide range of scientific knowledge is vital. Communication problems are manifest amongst the sciences as well as between them and the non-scientific world. Specialists are well aware of advances being made around the world in their own disciplines: however, they are often unaware of progress in other disciplines even in their own country and some are too modest (or too erudite) to discuss their work with laymen by way of the news media.

This report also seeks a wider audience. Scientific information is essential if the world environment is to be wisely managed and actions accorded the right priority. Much has already been achieved, and more could be done with existing knowledge if there is the socio-political will and the opportunity to apply it and if it is presented in a mode useful to policy makers. More information may well be needed about these issues, but scientific knowledge is not the only kind of information required. Decision-makers in international agencies and individual countries have to blend scientific, economic, and social factors in the evaluations that lead to policy. Just, therefore, as there must be communication among the many scientific disciplines that are required for the proper understanding of environmental processes, so there must be communication between scientists and those on whom administrative responsibility rests. To achieve this communication, the scientist must consider not only what knowledge to acquire, but how to present it to others. He must, above all, have an outward-looking attitude and recognize that his duty to the community does not always end when he has presented the results of his work to his own colleagues.

This report could not have been compiled without the willing co-operation of the many participants in the seven projects of the Mid-term Programme (Appendix C). Members of the Steering Committee shared in preparing the draft which was then reviewed by members of SCOPE National Committees and International Unions prior to the Third General Assembly of SCOPE. Martin W. Holdgate prepared Chapters 1 and 2 drawing on texts by Victor A. Kovda, Thomas F. Malone and others. In Chapter 3, the discussion of climate was prepared by R. E. Munn. The review of nitrogen, phosphorus, and sulphur was drafted by Erik Eriksson, Lennart Granat, Rolf Hallberg, Henning Rodhe, and Thomas Rosswall; the carbon and oxygen discussion was drawn from papers by Erik Eriksson and George Woodwell; Gordon C. Butler prepared the text on pollutants in the environment; Ralph O. Slatyer prepared the discussion of successional change in terrestrial vegetation; and Mohamed Kassas and Gilbert F. White drew together the materials on arid land irrigation. In Chapter 4, the discussion of problem identification was prepared by Ian Burton in collaboration with Gordon T. Goodman and R. E. Munn; the monitoring section was written by Gordon T. Goodman; the review of modelling was prepared by Francois N. Frenkiel; Ian Burton wrote the section on risk estimation with the help of Gordon C. Butler and also drafted the section on evaluation and communication. The discussion of standard setting is drawn from a report by Akin Mabogunje. The summary of ICSU activities in Chapter 5 was compiled with the assistance of Paul Sanborn and Melinda Cain. Martin W. Holdgate prepared the first draft of the concluding chapter, including materials by Thomas F. Malone. William Robertson IV served as secretary of the Steering Committee. Parts of the text will be published separately by the original authors under their own names.

The authors are indebted to many others in the member unions and committees of ICSU who have provided accounts of the activities of those bodies (Appendix B). The resulting report provides the first overview of the activities of ICSU in the field of environmental science. SCOPE thanks all those who have helped in the work of compilation.

PART I

Man's place in the biosphere

CHAPTER 1

Environmental Properties and Processes

The General Assembly of the International Council of Scientific Unions in October 1976, to which this Report is addressed, provides an opportunity for the scientific community to adopt a rational conceptual framework within which an orderly approach to environmental problems can be made. This development is timely. In recent years the world has endured reams of rhetoric, strident voices forecasting impending doom, and euphoric reassurances that there really is no problem. What is needed now is the most balanced consensus that the scientific community can achieve, based on a critical analysis, and, where possible, quantification of the problems. The aim of this report is to provide such a consensus – bearing in mind that the concept itself contains dangers. Diversity of viewpoint is an attribute which needs respect and careful treatment in the development of an intellectual framework. Scientists need not only consensus, to show the average balance of views in the informed scientific community, but also an indication of the range of informed opinion, as some measure of how far they may be wrong.

A. PERSPECTIVE

For this rational framework, a long-term perspective is essential. The earth started to form about 5 billion (10^9) years ago by accretion of cold particles chiefly of iron and magnesium silicates, iron, and graphite. It was too small to retain the primordial atmosphere of light gases. Gravitational collapse and radioactive decay caused the earth to heat up, and its material differentiated giving a central solid iron-nickel core, a liquid iron-silica shell, a mantle, and a lithosphere. In this process, degassing took place, forming a new atmosphere and hydrosphere. This atmosphere was devoid of free oxygen but contained methane, ammonia, carbon dioxide, and water vapour. Compounds of carbon, nitrogen, oxygen, and hydrogen were generated under the influence of energy sources such as lightning, solar radiation, or radioactive discharges, with mineral material serving as a template. The processes of life thus began about 3 billion years ago in the form of anaerobic chemoautotrophic organisms that were dependent upon ambient organic molecules for nourishment. The essential building blocks of life were formed and aggregated into cellular compartments. The fossil record shows that microscopic unicellular organisms occurred over 1,300 (and possibly over 1,700) million years ago, and the development of sexuality may have triggered marked increases in diversity and evolutionary rate.

Solar radiation and cosmic bombardment were primordially, and solar radiation is now, primary dynamic factors in the evolution and formation of the face of the planet. Tectonic and gravity forces, the original atmosphere, and the hydrosphere acted on the surface of magmatic rocks weathering their minerals to produce sand and silt, as well as colloidal and ionic solutions. Movement of the masses of suspended and dissolved mineral compounds in the atmosphere and redistribution of these compounds over the continent by water, sedimentation, and accumulation of salts in seas, ocean, and deserts occurred in the course of a billion years as part of very complicated processes. These abiotic phenomena still govern the geochemistry of our planet.

About two billion years ago, biological evolution took another revolutionary step. A few organisms succeeded in changing their mode of existence from one of dependence on fermentation and chemosynthesis to the more efficient mode of photosynthesis and respiration. This set the stage for the release of oxygen, the fixation of nitrogen, and further evolution as nuclei developed the capacity to divide by meiosis – a necessary precondition for higher life. As organisms that could not tolerate free oxygen were partially replaced by more efficient respiring forms, oxygen-mediating enzymes were added to the arsenal of chemical catalysts that govern metabolism and produce the structures prescribed by the DNA molecules. Carbon dioxide levels in the atmosphere were reduced, ozone appeared and formed a screen against incoming ultraviolet radiation, and organic deposits began to accumulate and form coal and oil fields.

The appearance of life and particularly the colonization of the land by plants profoundly changed the geochemical cycles. The original mineral surface was covered by green vegetation and film of humic soil, condensing large volumes of calories of fixed solar energy. Both land and ocean acquired a vast biomass of actively photosynthesizing plants and of animals and decomposers dependent on them. All this fundamentally changed the previous geochemistry of the earth. The cycles of a majority of chemical elements were re-oriented. New cycles of carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, and many other elements were formed. As a result a more complicated system took shape: the biosphere – an environment of life and a product of life. Mineral geochemical cycles were transformed into biogeochemical cycles, inseparable from the activities and metabolisms of living organisms.

In the continuing evolution of more advanced life forms, invertebrates appeared about 500 million years ago and vertebrates 400 million years ago. The dinosaurs reigned during the interval from 200 million years to 60 million years before the present. Man emerged less than five million years ago and so-called modern man dates back no more than a few tens of thousands of years. Yet modern society, in spite of its short history, acts now in some areas as a force comparable with or even stronger than forces of mineral nature and living matter. Geochemical and biogeochemical cycles are now subjected to powerful interference by man. Deviations, disturbances, and sometimes total destruction of important portions of the biosphere can follow, with immediate or delayed changes of a local, regional, continental, or global nature.

Against a summary of several billions of years of evolutionary history in a few sentences, what can we say of the future? Only that the remaining solar energy and the low probability of cosmic collisions suggest that the earth should be habitable for at least another hundred million years. Can the human species, which is astute enough to use modern plate tectonics to predict the shape of the continents 25 million years from now, learn so to manage itself during the next few decades that the habitability of the planet is assured?

B. KEY PROCESSES IN THE BIOSPHERE

The population/resources ratio of the world as a whole, and of some regions in particular, is shifting. Mounting population or rising demand for increasingly scarce resources make increasing demands on the biosphere, parts of which deteriorate while others are made more useful to humans. Four key processes which are essential for the functioning of the biosphere and therefore for the maintenance of the environment are:

(a) the conversion of light energy from the sun into the chemical energy which sustains plant and animal (including human) life;

(b) the biogeochemical and hydrological cycles by which essential mineral nutrients are passed through the biosphere to sustain plant, animal, and human life;

(c) the processes by which all living organisms pass through their life cycles multiply, and adapt themselves by continuing evolution; and

(d) the processes of perception, communication, processing, and transmission of information which make possible the interaction of living things with each other and with their environment.

The natural environment is a complex, interacting system of physical chemical, and biological components. Solar energy provides the driving force for many of the chemical and physical processes as well as biological activities. Atmospheric and oceanic circulation, weathering of rocks, and habitat conditions for all organisms depend intimately on the levels of radiation from the sun.

Many habitat conditions are only predictable to a certain degree. Superimposed on the regular seasonal and diurnal cycles there are fluctuations which can be conveniently described as random, since so far their prediction is only possible in terms of statistical probability rather than as specific events. These fluctuations cover a wide range of time scales, embracing short-lived turbulent phenomena and long-term climatic oscillations. Climate, in particular, has great natural variability from place to place, decade to decade, and even over hundreds of thousands of years as the repeated Pleistocene glaciations demonstrate. Yet life on earth has been possible only because global climate has remained, within certain limits, relatively constant over several thousand million years. Climatic changes obviously affect all living organisms, and to the natural fluctuations are now added the possible effects of human activities. Such effects are well marked on a local scale, for example where 'heat islands' are created over cities, but are more difficult to detect regionally, and probably are not yet visible globally despite rising levels of atmospheric carbon dioxide and changes in the amount of particulate matter suspended in the air. One major group of environmental problems arises from this unpredictability of the climate, whose trends and oscillations can affect agricultural production, energy consumption, aridity, and biogeochemical processes over large areas. Projects I, II, V, VI, and VII of the SCOPE Mid-term Programme touch on these applications, but the main thrust of international effort is within the ICSU-World Meteorological Organisation (WMO) Global Atmospheric Research Programme (GARP).

Solar energy, harnessed by photosynthesis, provides the driving force for all ecological processes. There are limits to the capacity of green plants to trap incoming solar radiation and use it to produce carbohydrates. It has been calculated that no more than 5 percent of solar radiation reaching the earth's surface today is absorbed by plants. Much of this is re-radiated. Only a very small fraction is actually converted into carbohydrates and made available as a chemical energy source for plants and animal consumers. One group of contemporary human problems surrounds the possibility of developing strains of plants with higher photosynthetic efficiency, a greater capacity to intercept radiation, or a wider environmental tolerance, particularly to limited water, so that the 'green area' of the planet is expanded, thereby enhancing potential food production for humans and livestock. The possibility of expanding the land area under cultivation is, however, generally thought to be small, and losses appear to balance the gains from irrigation and new cultivation.

In all terrestrial habitats the soil is of vital importance. The soil serves as an energy, water, and nutrient storage system which smooths the effects of fluctuations in rainfall and other climatic variables. It provides a habitat for organisms decomposing organic remains and recycling the substances they contain. In the soil there are complex interactions between biological and inorganic components of the system. Soils depend on their living microflora and fauna, and on the vegetation that covers them, for their properties and have taken millennia to develop to maturity. Drastic changes in vegetation cover can lead to destruction of soils and losses of nutrients and fertility: a phenomenon frequently recorded in the past and still likely to accompany unwise development of new lands for cultivation. The accelerated growth in the network of towns, villages, industries, and communications systems today is often accompanied by virtually irreversible soil loss. Desertification, erosion by wind, and salinity and waterlogging of over-irrigated land are also major causes of loss. Probably 25 million hectares of land are being lost annually from such causes, many of them unnecessarily.

A proportion of the plant material in the world is consumed directly by herbivorous animals, among which invertebrate species substantially outnumber the vertebrates. Man's livestock and the wild species he crops are in a minority. In most cases it takes between 4 and 10 kilograms of plant material to make one kilogram of even the most efficient herbivore. There is a comparable loss in the conversion of the flesh of herbivores to the flesh of those predators that consume them. Moreover, it is not the fate of every plant to be eaten or every herbivore to be taken by a predator. About 80 percent of the energy fixed at each level in the system is ultimately released by the death of the organism to the decomposers that return it to constituent inorganic materials and nutrients. The bulk of the decomposers are microorganisms, the total biomass of which is estimated to be of the same order of magnitude as that of the animals. The essential, positive role of microorganisms in biogeochemical cycles, in waste treatment, in agriculture, and in industry is often underestimated when compared with their pathogenic effects on men.

Just as the features of any plant or animal community at any time are the outcome of many interacting factors and components, so the continued production of new organisms by evolution is altering the composition of ecosystems. Human intervention further modifies the dynamics of environmental systems and the context within which such evolution proceeds, and so accentuates these processes. Genetic adaptability depends on the presence of genetic variation (a large gene pool) and genetic recombination (by sexual reproduction). Only those species having a large gene pool and capable of rapid recombination are likely to survive in a rapidly changing environment.

C. MAN'S USE OF THE ENVIRONMENT

Man, as a herbivore and carnivore with a very wide dietary range, is remarkably well equipped to exploit the variable habitats of the world, and as a hunter, fisherman, and forager he consumes a substantial number of different plant and animal species. The processes of domestication, however, have concentrated in recent times on only about 100 species of plants and a smaller number of animals, while the domestication of the microbial world started only a hundred years ago. Another group of contemporary environmental problems surrounds the question of how food production can be improved by the wiser use of the plant, animal, and microbial diversity.

One way of doing this would be to rationalize the consumption of animal matter, the production of which – in comparison with plant food production – is both less efficient in terms of energy conversion and more stressful in terms of environmental impact. There are, however, parts of the world, unsuited for cultivation, in which an animal crop – whether from wild or domesticated species – is the wisest form of land use. Many affluent national societies are wasteful in their nutritional use of converted solar energy, both because of their unnecessarily high meat consumption and by their habit of reprocessing valuable animal protein sources (such as milk or fish) through herbivores in order to produce more desirable food such as meat. With mounting world population it is questionable whether this pattern of use can continue and there is a considerable scientific effort, of which SCOPE and ICSU must take cognisance, seeking to increase the equitable use of world food resources and to provide more efficient ways of securing a nutritionally adequate diet for the whole population of the planet.

Another approach which has considerable promise is to expand the range of species which are cropped and particularly utilize species which were not attractive to man in the past but which are capable of providing a higher productivity on areas of land not suited to traditional crops. Early man was dependent on those plants that produced substantial volumes of readily digestible food uncontaminated by toxic or unpleasant oils or alkaloids. He was also dependent upon herbivores that were capable of relatively easy management. He tended to carry out genetic improvements within the narrow range of stock domesticated early in history. The number of new additions to the total range of livestock within recent centuries, at a time when scientific knowledge has expanded dramatically, has been extraordinarily small. In recent years, research has shown that a number of large wild ungulates are capable of producing meat using unimproved natural vegetation on the same kind of scale as improved domestic stock eating much more heavily managed and altered vegetation. Methods of extracting leaf protein from a range of plants have opened up the possibility of cropping wild self-sustaining vegetation without the management effort of intensive cultivation – although the energy costs of these techniques of protein extraction are at present high. There is a need for critical ecological study of these alternative ways of harnessing the energy resources of the world for human welfare. They link to questions of the conservation of the world's genetic resources which clearly become of added importance with the possibility of more direct utilization of a greater number of species.

This whole question of improved food production is linked to another, namely the extent to which environmental systems possess a degree of homoeostasis: that is a self-regulating capability. In the natural environment the composition and appearance of types of vegetation and their associated fauna are the result of a great number of interacting factors, and they inevitably display change in response to fluctuations in climate, as well as to the activities of man. Sometimes, as when a lake fills in with sediment, there is a natural succession, each vegetation type building up a layer of peat and altering the habitat in favour of shallower rooting species and ultimately of woodland. These successional processes are, however, slow and at any time most natural vegetation appears to possess a degree of stability and resilience. The 'resilience' of a system is a measure of its capacity to withstand environmental stresses. Pressed beyond certain limits, stresses can no longer be absorbed and an ecosystem will change rapidly to a different configuration. For example, if a semi-arid grassland is over-grazed, a point is reached at which it rapidly becomes bare and eroded, and natural recovery is then either very slow or impossible. Exploited populations can similarly be so depressed by over-cropping that their recovery takes many decades, as has recently been demonstrated by the larger whales and by some oceanic fisheries.

There is argument over the extent to which the resilience of a system is related to its species diversity. In relatively constant and favourable environments a large number of species is generally present and the system is characterized by a high order of interspecific competition. Under these circumstances, diversity does appear to be related to stability: perturbations, such as selective treecutting, that fall short of gross physical disruption are followed by changes in the relative abundance of component species rather than alterations in the overall structure of vegetation and fauna. Moreover, the greater the potential productivity of a site, the faster it generally recovers after disturbance. In other habitats such as deserts or polar and alpine environments, where physical disturbance of the habitat and environmental stress are great, the range of species present is much less, yet species are often remarkably constant in their presence for decades, if not centuries. In these cases, there is apparent stability despite a low level of diversity, probably because environmental conditions remain much the same over long periods and all the species present are adapted to them. However, human impact may cause particularly severe damage in these highly stressed areas and recovery is very slow.

In areas such as National Parks and equivalent reserves, or lands under ecologically sound forest and range management techniques, there is usually a low energy supplement associated with human activity. In contrast, there is usually a high energy supplement in intensively used rural and urban lands. In between is a range of increasing habitat modification usually associated with an increasing amount of energy input and a decreasing dependence on the natural environment and biota.

Although these phenomena are not always linked (for example, low energy input rural land-use is, in many developing countries, also associated with marked habitat modification), it is apparent that as the degree of habitat modification increases, and as exotic species are substituted for natural species, a knowledge of the structural and functional relationships of the original ecosystems becomes less relevant to the management of the modified systems. These systems can nonetheless be retained in a highly productive and stable state, as is evident in many deforested and drained areas of Western Europe and in ancient irrigated systems of central and Southeast Asia. On the other hand, in areas that are utilized essentially as managed natural systems, a knowledge of the original structural and functional relationships is probably important as a foundation for effective long-term management, consistent with both conservation and maintenance of productivity. These systems include many terrestrial woodland ecosystems and arid or cold regions, as well as areas that have been difficult to cultivate because of topography, high water table, or other factors. They also include many aquatic ecosystems, including those of the sea.

The oceans cover 70 percent of the earth's surface and provide about 70 million tonnes per year of high-protein food. Hitherto they have been exploited by methods that are essentially mechanized and often competitive hunting rather than carefully managed cropping, and some resources have, as a consequence, been wasted by over-exploitation. It is believed by some investigators that, with proper management, the yield from the oceans could be greatly expanded and this production sustained. New species (such as the krill of the Antarctic) are being cropped as well as the more traditional fisheries. This expansion in the use of the seas must be based on adequate scientific knowledge, relating the productivity of exploited stocks to overall ecological balance. In addition, account needs to be taken of the interplay between the exploitation of oceanic life for food and the expanding development of seabed energy and mineral resources The Scientific Committee on Oceanic Research (SCOR) within ICSU, and the Food and Agricultural Organisation (FAO) among intergovernmental agencies play a major part here. Marine resource management and marine pollution have received little attention from SCOPE and are only referred to briefly in this report.

Ecosystems traditionally utilized for agriculture and fisheries are being intensively studied by FAO and many other governmental and non-governmental international and national organizations. By comparison, the managed natural systems have received relatively little attention, yet when they are used unwisely by man they rapidly become unstable, with associated severe, and sometimes essentially irreversible, changes. For these reasons, Project II in SCOPE's Mid-term Programme concentrates on managed natural ecosystems.

Modern agriculture has arisen through a process of increasingly intensive injection of human management effort into the environment. Forest clearance replaces a diverse system, with a high order of competition, substantial proportion of the total nutrients locked up in the standing crop, and in which annual production represents a relatively small proportion of the total living matter in the system, by one much more typical of earlier successional stages. This is commonly a grassland, where the annual production is large in proportion to the standing crop or where the whole system is made up of annual species. A high proportion of the nutrients cycles through the system each year. There is much more rapid change and a much greater potential for change if human management is withdrawn. Commonly (but not invariably) abandonment of management is followed by resumption of the successional process back to forest. Cornfields and pastures are maintained as such in most temperate regions by the continuity of human management and where this is withdrawn woodland may quickly return. Intensively managed crops are commonly composed of but a single species, and management effort is needed to exclude other plants and those invertebrate and other pests which feed on the crop.

Modern agricultural and urban systems have replaced an ecological situation in which nutrients were cycled from plant to herbivore to carnivore and back from all of these to the soil by decomposers within one general area by a more linear flow of nutrients through the transport of plant material or meat from the countryside to the city and the discharge of the nutrients down the sewage systems to the sea. Phosphate, for example, is only slowly replenished from the environment, coming from the sea or from the weathering of phosphatic rock. In modern agricultural management it has been necessary to take deliberate steps to replace the nutrients lost if fertility is to be sustained. These systems operate efficiently in the highly managed agriculture of wealthy countries. In contrast, the extension of agricultural systems onto new lands in countries without a substantial technical and economic base has often been accompanied by the wastage of living resources and nutrients and the development of unstable types of vegetation with a lower productivity and higher incidence of soil erosion than is desirable or necessary. Another group of modern environmental problems stems from this basic fact that much of the land now being developed for agriculture in the tropics and subtropics does not have an inherently high natural fertility, tends to suffer from problems of erosion or salinity, and requires considerable management from the outset if such fertility is to be sustained or enhanced. Traditional methods of agricultural development applied to fertile land in developed countries or adapted to a shifting cultivation system in which land is returned to be fallowed under forest for decades are not appropriate to the needs of rapid agricultural development where populations are mounting.

One group of modern environmental problems stems from man's need to use the energy resources of the biosphere more wisely and avoid activities that will cause a loss of stability, a wastage of genetic diversity and nutrients, and a consequential impaired productivity. There is a conflict here. Many agriculturalists consider that maximum productivity can only be achieved by the most intensive cultivation system that can be devised and by maintaining stability through crop protection and husbandry techniques. Such systems clearly conflict with the maintenance of genetic diversity; they are not balanced by natural factors; and the modified ecosystems may not be as tolerant of stress.

The need to develop new land at all is a reflection of man's mounting population and poses further significant environmental problems. It is a feature of all animal populations that their numbers are ultimately limited. In the prehistoric past, man has been no exception to this rule. Some of his traditional limiting factors have been much the same as in animal communities, namely competition for food and other resources, disease, and the struggle for living space and societal status. These have sometimes found their expression in famine and warfare. In contrast, even some simple cultures have evolved effective social checks on human numbers, Much of the world has for the present time escaped from the original zoological population limits through better agriculture backed by industrial technology, a stability of national frontiers, and medical technology. The result has been an unparalleled growth in the numbers of the human species, although this has not been spread evenly over the globe or associated everywhere with the same advances in living standards.

It is now universally agreed that every effort must be made to prevent the collapse of societies in which the original limiting factors would again take their toll. This requires the development of humane, self-imposed controls on human fertility, adjusting populations to the appropriate levels in different countries. Medical, agricultural, economic, and industrial development, education, and enhanced production may help this process by improving the standard of living and satisfaction with life which, in turn, provides the most certain and effective incentive to population regulation. Many of these issues go far wider than the expertise of ICSU or SCOPE. However, there are still inadequacies in scientific knowledge, and it might be a task of SCOPE to aid in understanding the basic dynamics of human populations, to explain the interrelationships between man and environment, and to consider the situation in which the natural limiting factors are likely to come into operation most swiftly and with greatest impact if societies fail to attain the goals of social and behavioural population control.

Pollution is one offshoot of man's mounting numbers and increased industrial technology: its nature and extent depends on the type of society and technology, the levels of scientific knowledge, and the degree of determination to impose controls even if they reduce profits. Those pollutants that are on an upward trend in the world as a whole have not all been demonstrated to be potentially hazardous on a global scale. Most pollutant problems today are localized, creating 'hot spots' in small areas of the biosphere, where they have caused acute damage to small groups of people and to crops, livestock, and natural flora and fauna and where some of the incidents have been tragic. Some pollutant problems recur over the world (a phenomenon which is sometimes called 'the measles effect'). Chemical variables, including pollutants, are among the factors which affect the growth and performance of crops, the flow of energy to man, and the well-being of man himself, and for this reason SCOPE must attach importance to pollution problems and must consider these within the total ecological context.

The overall lesson is that environmental systems must be looked on as dynamic and interacting wholes. The basic patterns of energy flow are fundamental. So is an appreciation that man, is his widening impact on the world, has reduced the diversity of natural systems and taken upon himself an increasing obligation to regulate the systems he has modified so as to prevent their changing to configurations less suited to the support of human life. Man's generation of pollution, although it has been partly counterbalanced by the development of technology capable of controlling that pollution, nonetheless poses a further demand for management effort. Industry is now acceptable on its present scale in some areas simply because of the amount of endeavour devoted to its regulation, so that the desirable products are obtained without the unacceptable side-effects. As human population mounts and technology creates the products that in some societies are considered essential for a secure and high standard of living, the proportion of the environment managed by man is bound to expand. As a result, the naturally self-regulating unmanaged component on which man nonetheless depends for the recycling of nutrients, the stability of atmospheric systems, and the maintenance of genetic diversity is bound to contract. It is clearly essential that man's numbers be in balance with the environment on a national or regional basis at a level where human needs and aspirations are satisfied and the stability and diversity of the biosphere are sustained. This argument stands separately from the largely unscientific but strongly held social viewpoint in many areas of the world that an interrelationship between man and something approximating to wild nature is desirable as a part of the total sum of human happiness and hence a legitimate social objective.

D. MAN'S ROLE WITHIN THE BIOSPHERE

Environmental problems, in the sense that human impact has altered natural ecological processes, have existed almost as long as man himself. Fire, deforestation, and massive predation characterized some of the earliest human activities. Until man discovered sources of non-somatic energy however, particularly from fossil fuels, human populations remained relatively small, and environmental impact relatively local. With the scientific-technological-industrial revolution has come an exponential increase in population growth, and momentous increase in the environmental demands of many individuals. These are associated not only with basic needs for food and shelter, but also with the immense socio-cultural infrastructure that some peoples have created to satisfy their perceived needs for goods and services.

Human populations, personal needs, and agricultural and industrial production have all increased more rapidly than has the awareness of their impact. The ability to enhance human nutrition, fertility, and longevity has increased much more rapidly than the consciousness of the need to avoid excessive population pressures. The ability to increase the supply of goods and services by massive inputs of raw material, technology, and energy has occurred much more rapidly than the consciousness that these activities are liable to produce by-products and side-effects which can have deleterious effects on the environment. All this has been exacerbated by growing social and economic inequalities at both national and international levels in many regions of the world.

By tapping the stored solar energy available in fossil fuels and the power of the atom, by manipulating natural materials and synthesizing new ones, by an enhanced understanding of life processes, genetic laws and the chemical nature of a gene, and by the recently acquired and rapidly expanding capacity to handle information, the human race has introduced significant perturbations in these natural processes. The implications are many:

(a) The capacity to use energy multiplies the work-performing capability of an individual hundreds of times and makes modern transportation, construction, and manufacturing possible. It also multiplies man's potential destructive effect on the environment.

(b) The capacity to manipulate materials provides a whole host of new and useful consumer goods, ranging from petrochemical products to hand computers. It makes possible the 'Green Revolution' by providing new varieties of seeds, insecticides, and fertilizers. It is also the source of air, water, and land pollution that can pose a hazard to human life and comfort.

(c) The capacity to influence biological processes has led to new and more productive strains of grain and breeds of animals, and it has prolonged human life expectancy. It has also aggravated the explosively expanding demands of more and more people for limited resources. It is posing problems of genetic engineering, DNA recombination, and the ethical practice of medicine. It has also led many people to stress the need for environmental and genetic conservation.

(d) The capacity to handle information may turn out to have the most portentous impact of all. Scientists can observe parts of the universe veiled from the human eye. They can manipulate machines millions of kilometers away. They can be in instant audio and visual communication with millions

> of our fellow men; they can perform calculations and solve problems that were impossible, in a practical sense, just a few years ago. These skills impose enormous ethical demands, and society needs to develop better ways of ensuring that they are applied to improve man's use of the environment, rather than increase hazards.

These skills bring within reach a theoretical capacity to greatly enlarge, over a few decades, the transformation of the natural resources of the earth into the goods and services necessary to sustain life and to satisfy human aspirations. Thus, the possibility, which requires social action if it is to be realized, of a better life for all in the near-term future is enormously increased. On the other hand, together with this expansion in man's influence, there will almost certainly be a doubling in the world population – also over a period of decades. It is possible that the 'carrying capacity' of the earth may be exceeded with tragic consequences.

The capacity of earth to support human population evidently depends on a balance between population density and life style on the one hand and available natural resources on the other. It is affected not only by primary production and by available energy sources, but also by the level of scientific knowledge leading to their wise use. The sun can be regarded as a renewable energy resource but has not, so far, been used directly for technological purposes simply because of the wide availability and cheapness of concentrated, stored solar energy in non-renewable forms such as coal and oil. Today, people are increasingly occupied with finding replacements for these fossil fuels when economically extractable reserves are exhausted. The potential of nuclear energy resources is large but their use brings waste disposal problems which have not yet been solved satisfactorily.

Any breakdown in carrying capacity would not be likely to strike the entire world at once. The world is heterogeneous in structure and climate. There is enormous variability in environments and ecosystems, and biogeochemical cycles vary likewise. These variations are manifest as constraints on human society. The environment, agriculture, and type of settlement experienced by an inhabitant of the tropics inevitably differs from that of the dweller in temperate or sub-polar zones. Fertility of soil, the availability of water, minerals, and non-nuclear energy sources, and exposure to the natural hazards of volcanic or climatic variability cannot be made the same everywhere. Taken together with the enormous differences between and within human societies, these variations lead unavoidably to variations in the nature and magnitude of environmental problems and human priorities over the globe. Although the implication is that environmental stresses will be manifest initially at a regional level, the local tensions thus created may nonetheless spill over to create wider dangers.

Global generalizations are dangerous if they over-simplify and lead to unreal solutions. However, there are certain social issues, applicable to different degrees in different places but to some extent everywhere, which need to be examined and related rationally to environmental factors. Among these are:

(a) the need for a concerted effort to increase and sustain food production so that the large proportion of the present human population that is inadequately fed approaches a reasonable standard of nutrition, and provision is made for the hundreds of millions of extra individuals that will need food during the next few decades;

(b) the need to bring human populations into balance with their environment in a manner compatible with individual choices and with the aspirations of those nations which still need or can tolerate more people;

(c) the need to reduce the disparity in the per capita rate of converting natural resources into goods and services. The great, and in some areas widening, gaps between the per capita earnings of sections of the world's population are widely considered unacceptable as is the growing gap between rich and poor within many countries. Further substantial increases in material consumption by the more affluent individuals in all countries is simply not compatible with the total needs of present and future generations;

(d) the need for rational utilization of natural resources, taking realistic account of national rights but providing adequately for both present and prospective inhabitants of the earth. Conservation of resources and of energy (by recycling and other means) is likely to be increasingly important;

(e) the need to conserve meaningful samples of types of ecosystems in as unaltered a state as possible, not only as national heritages, but more importantly as reservoirs of information about natural processes and as natural repositories of unique and irreplaceable genetic material;

(f) the need for a wiser approach to the design of human settlements. The process of urbanization may be irreversible, but in some cities the disadvantages of aggregation of family units outweigh the advantages. More attention needs to be given to the creation of towns organized to supply employment and essential services and to sustain social and environmental quality;

(g) the need to reduce the disparity in scientific and technological manpower. While many of the more serious environmental problems of nutrition, health, and housing manifest themselves most strongly in the developing countries, the problem-solving capability is largely concentrated in the developed countries;

(h) the need for adequate quality in man's physical environment, and hence action to combat present inequalities. This involves considerations of health, education, economics, and aesthetics which, in turn, determine our management of air, land, and water; and

(i) the need for peace and security in life and property in the face of natural and man-made hazards. As the world's population density increases

> accompanied by increase in the capital value of property and dependence upon technology, the potential for catastrophe enlarges.

Many of these issues go beyond the role of SCOPE, and indeed, that of science, but science must organize itself to foresee the problems and contribute to their solution.

It is within the context of these basic environmental processes and properties and man's interaction with them – and needs from them – that Chapters 2, 3, and 4 have been developed and that SCOPE's plans for future work are put forward.

CHAPTER 2

The Role of Science in Environmental Policy

A. STEPS TOWARDS A POLICY

Successful action on an environmental issue normally demands that four conditions be met:

(a) there is adequate qualitative and quantitative knowledge about its causes and trends or the means to obtain that knowledge;

(b) the issue is recognized as a genuine environmental problem and sufficiently important to arouse concern;

(c) there is social and technological capability to carry out essential action effectively;

(d) there is sufficient determination and resources within the community to make the action succeed.

It is evident from this analysis that while scientific information is essential, successful action demands more than science and scientists can alone contribute. This is recognized in the analysis of assessment of environmental risk prepared by SCOPE as a part of Mid-term Project VII.

The role of the scientist in this process is first to submit the problem to analysis, defining and clarifying its exact nature. A second step should be the quantitative prediction of the scale of the impact, both in environmental and social terms, and including a specific indication of uncertainty. A further logical step involves the development of alternative strategies for dealing with the problem and assessing the costs and benefits of each. This third step has three components:

(a) evaluation of available technology;

(b) statement of options;

(c) discussion of the implications of the options for environmental planning decisions.

Clearly the role of the scientific community is most important for the recognition and definition of issues and becomes less relevant in the final stage of executive action to carry out a management choice.

Environmental issues to which science can make profound contributions, may be grouped in three categories:

(a) those solved successfully by the application of existing scientific knowledge;

(b) those which existing knowledge could solve but where social or economic factors limit action;

(c) those requiring more scientific knowledge.

An example of the first category is provided by many communicable diseases. There are countries in which a number of these have been so successfully overcome that they are no longer regarded as environmental issues – even though they remain among the major problems of environmental health in other parts of the world. In many cases successful action has come not only from the direct application of biomedical knowledge but through higher standards of public hygiene and housing, as a more or less indirect outcome of social development or better nutrition. These improvements have made a major contribution to the solution of population growth problems. These diseases also illustrate another need: continued scientific vigilance to detect new hazards from the infectious agents involved, arising for example from modified resistance in man and other target organisms.

The second category includes many examples where the application of scientific knowledge has produced substantial benefits but on a limited scale. Wider and more beneficial action depends on social determinants and choices. For example, integrated pest control could be more widely applied, with consequent reduction in the environmental hazards due to excessive pesticide application, but is inhibited by the high costs and effects on patterns of industrial investment. Fluidized bed desulphurization can increase combustion efficiency in coal-burning power stations and reduce pollution, but is nonetheless being neglected because of the economic cost of converting existing installations. Many cities contain large blocks of high-rise flats having designs that offer a less than ideal social, ecological, and psychological environment for their inhabitants, but social and economic factors inhibit their demolition, and in many towns such blocks are still being built.

It is evident that the highest priority for further research should be given to problems where lack of scientific knowledge is the limiting factor. Among the areas which may merit priority treatment are the study of natural processes, which must be understood before one can begin to analyse processes perturbed by man; the search for new energy sources and more economic energy transformations; the development of more productive and efficient man-managed biological systems, without increasing the energy subsidy to them; the protection of soil from deterioration through misuse or pollution; the refinement of methods of improving the application of scientific findings; and the development of better methods of detecting, evaluating, and preventing risks to man, other organisms, or the processes of the biosphere.

It is equally evident from this analysis that it is wasteful to use scientific investigations, including basic research, as a 'displacement activity'. Many problems are capable of easement, if not of solution, using existing knowledge – assuming that socio-economic conditions allow the use of this knowledge and that the social will is there. If a Government is not prepared to act, but judges it expedient for some action to be manifest, there is a temptation to fall back on a scientific enquiry or study to explore those parts of the problem that are least well understood, or to 'reappraise' the whole. Such actions can be pointless and wasteful of expert resources. Before studies are undertaken, it is essential to assess whether the limiting factor is genuinely lack of scientific knowledge or a lack of social determination and response. If it is the latter the fault may lie in the systems of communication between scientists and policy-makers, and the onus may lie on the scientists not to do more research but to present their knowledge in a clearer format, suited to the policy-makers in the community. The scientist has a responsibility not only to acquire knowledge but to communicate it – to other components of the community as well as to his fellow professionals. This is the dominant theme of Project VII, in the Mid-term Programme of SCOPE.

B. THE RECOGNITION OF PROBLEMS

The sequence for solving environmental problems clearly demands collaboration between scientists, economists, legal experts, sociologists, health authorities, engineers, administrators, and the public. The essence of this co-operative process is communication. The efficiency of any problem management process must rest first on its being in touch with events in the natural world through monitoring and surveillance systems, and events in society through a monitoring of the channels of communications within the general public and within Government. Communication between the problem definer and other components of society is equally vital and at the end of the exercise, action on the problem has to be justified to those whose job it is to undertake the overall balance of social policy which must mix economic, environmental, technological, and other social factors. There are numerous examples of how this pattern has worked through in practice.

Very commonly, organizations that are expected to detect problems act largely in response to situations first made evident through unexpected environmental change (for example, through unexpected deaths among wildlife or unexplained sicknesses in communities) highlighted by the mass media. In the past this has been the predominant cause of problem recognition and the one producing most dramatic responses. Examples include:

(a) airborne sulphur and smoke, associated with 3,000 to 4,000 excess deaths in the London fog of 1952–53;

(b) methyl mercury as a cause of 'Minamata disease' in Japan;

(c) polychlorinated biphenyls involved in food poisoning from contaminated rice oil in Japan or associated with the deaths of about 12,000 sea birds in the Irish Sea in 1969; and

(d) persistent organochlorine pesticide residues associated with declining populations of predatory birds in Europe in the 1950's and 1960's.

It is important that scientific bodies such as SCOPE do not simply respond to requests from governments for advice and analysis, but act to identify prospective problems through the processes of search, recognition, definition, and analysis. Five separate ways of identifying problems have been noted:

(a) convening an expert meeting, the quality of whose results depends critically on the number, ability, and interactions of the experts present;

(b) feedback from experience, whether through national agencies or otherwise; it being recognized that action by a competent national agency is in itself an adequate testimony to the existence of concern;

(c) deduction from first principles by the scientific community: a highly desirable and insufficiently exercised process;

(d) observation of an unexplained event like the illness of people or the mass deaths of wildlife. It is undesirable that this be a main means of problem recognition but probably inevitable that it will recur from time to time however gifted the scientific community is in its logical deductions;

(e) deliberate definition of problems through research, the screening and testing of new products, and monitoring including the systematic monitoring of human health. This is a highly desirable way of recognizing problems, and a method which hopefully will increasingly prevail as new questions arise.

The five approaches cited above fall into two groups. Approach (c) is the theoretical one; (b), (d), and (e) together constitute practical means from which most comtemporary problem recognition comes. Commonly, approach (a) is used as a first stage in evaluation of issues noted through one of the other channels.

In the past, many organizations seeking to define environmental problems have indulged in cataloguing exercises. They have brought together groups of people with expertise in particular fields and in a relatively brief period have listed what seemed to those individuals as being of particular importance. Often such meetings involve the uncritical acceptance of the expertise of the individuals present because there is little time to test the assertions of any contributor by a studied debate, or to obtain endorsement by referring the potential problem to a wider circle of knowledgeable specialists.

Such current processes of problem recognition thus have certain potential drawbacks. They may involve conflicts of expert assertion. They tend to have a subjective element weighted to the standing of recognized authorities. It is difficult to quantify the process. It must be recognized that sampling problems are as acute here as in many other of the natural environmental fields. Very often a logical sampling approach has not been adopted. For example, if the expert meeting is to be used as a means of problem recognition, it would be sensible to set up a series of such meetings deliberately designed to define the variability of opinions, and more use could be made of scenario and judgmental methods which are in course of refinement. A stratified random approach could be made using the various groupings of scientists as units in the stratification. For example, one could select at random a series of members of various learned societies rather than invite those societies to nominate experts. One drawback of such a system would be that it would by-pass the traditional process of screening capability and knowledge.

The result of this traditional process is, however, the suppression of the variability in the views of the scientific world and its replacement by something akin to a weighted average, through the statement of the opinions of those in the national scientific community who happen to have at the particular time the greatest influence on established national thought. SCOPE might well take this whole question of the sampling of the views of the world's scientific community in problem recognition seriously and look at the techniques available, recognizing that it is at least as important to define the range of variation in opinion as to settle to an average view.

Stratification could similarly be achieved using the different international agencies which have been concerned in problem recognition. For example, there are groups concerned primarily with conservation which tend to adopt an environmentalist or protectionist view: examples include the Friends of the Earth, the Conservation Foundation, and the International Union for Conservation of Nature (IUCN). There are intergovernmental organizations in the developed world, such as the Organisation for Economic Cooperation and Development (OECD), the European Economic Community (EEC), or the Economic Commission for Europe (ECE). There are global intergovernmental organizations with varying degrees of specialization such as the United Nations Environment Programme (UNEP), FAO, the World Health Organization (WHO), WMO, or the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Finally, there are industrial groups concerned with particular aspects such as the petroleum or iron and steel industries. It would be possible to superimpose the lists of problems recognized by the different organizations and see how far they agreed. A recent study of this kind by the senior advisers to Governments on environmental problems in ECE suggests that there is considerable agreement, but the effect can only be to stress the recognized problems and under-reflect the cryptic ones. Ten years ago it is unlikely that this exercise would have revealed any potential problem over polychlorinated biphenyls or chlorofluorocarbons, yet both would occur on any listing compiled by this method today.

Until the recent sessions of the United Nations Governing Council on Environmental Programmes, international evaluations of environmental problems reflected, to an overwhelming extent, the experience of developed countries, although the environmental problems divined by developing countries inevitably differed. Many such countries not only have pressing local problems of a kind no longer acute in developed nations, but in consequence place less emphasis on slow and relatively ill-defined global changes. This has been one of the principal lessons to the world community from the Stockholm Conference, and has, incidentally, led to the inclusion in the SCOPE Mid-term Programme of a project on human settlement and another on the problems of arid lands irrigation, both of high priority in developing countries. The full range of problems of the environment will not be recognized, and still less solved, unless the diversity in man's approach to the environment is taken into full account.

The situation is aggravated by the imbalance in the distribution of the world's scientists. For example, at the International Botanical Congress held in Leningrad in 1975, it was noted that the tropics hold 70 to 90 percent of the plant species on earth, but 90 percent of botanical taxonomic work is done on temperate plants. Tropical species are becoming extinct before they are discovered, as forests are cleared for cultivation, with a consequent potential loss of important sources of food, fibre, or drugs.

At the same time, the natural preoccupation of developing countries with the immediate priorities of development should not lead to the neglect of the lessons which are apparent in countries which went through those processes of development at an earlier period. There is a need to put environmental planning on a sound footing in all countries. There are concrete examples showing that it would be very dangerous to overlook the environmental hazards, for example to soil fertility, that could result from unwise development.

C. THE EVALUATION OF PROBLEMS

Even after a list of potential problems has been compiled, relative priorities cannot be assigned without analysis and quantification. This is by no means easy, as a glance at the diversity of the problems in the priority areas defined by the United Nations Environment Programme (UNEP) shows. Each has a different socio-economic mix. SCOPE may be mainly concerned with the scientific components but cannot evade the blend of other considerations that intrude.

These components may be seen as a series of factors, sometimes varying quite independently of one another, sometimes highly interactive but always at some point on a scale from high to low. Each problem will be a combination of these. Among the criteria that can be recognized as important are the following:

(a) The nuisance scale of the problem. Is it capable of causing serious harm to individuals or populations at risk via sickness or death? Or is it less severe, but nonetheless a serious nuisance, e.g., noise or smells, or less severe still, e.g., visual ugliness. It is important to recognize that every society, depending on socio-economic or cultural considerations will scale problems differently because of inherently differing value-judgment systems.

(b) Perception of problems. At one extreme, the problem may be thoroughly and widely perceived, grading through to a problem which is being missed completely. Moreover, there may be differences in the perception of different sectors of the scientific community, and there is likely to be even more divergence within the general public, differently influenced by the communications media of press and television. The Government sector may well be at yet another point on the scale. The result is that there are many gaps in understanding. These may make each sector act differently, in response to their own particular level of perception of the problem. Funding for further work on the problem may be hard to obtain if the scientists are too far ahead of the public or government. The public may even appear to be complacent, e.g., over traffic accidents or smoking and health risks. Conversely, funds may be squandered on trivial problems or the scientific community may appear indifferent while the public is deeply concerned, e.g., over the medical significance of lead emitted from vehicles.

(c) Ease of recognition. Is the problem readily monitored directly by the human senses as in the case of noise or squalor? Or is the problem cryptic, requiring sensitive instruments and complex assessment procedures to recognize and define it, e.g., radiation hazards?

(d) Quantitative measurement scale. Some problems are easily measurable, e.g., many potentially harmful chemicals in air or drinking water. Others defy quantification, e.g., unpleasant tasting water or tainted air. The quality-of-life concept is a readily grasped reality, but at present it is impossible to measure on a scale common to all sectors of human society.

(e) Space-time scales. Is the problem global, regional, or local? Is it truly homogeneous or confined to separate 'hot spots' of greater or lesser frequency? Are these local problems increasing so greatly in number and extent that they are becoming regional or even global? Is it a long-term or short-term problem, and are its effects largely irreversible or evanescent when the causal circumstances are stopped? Conversely, how long is the response time after the causal circumstances begin to operate? These are very important considerations which separate very severe from trivial problems and may cause us to think carefully before taking an environmental risk.

(f) Ease of solution. Can the problem be solved readily or is it intractable?

These and similar considerations affect our assessment of what constitutes a problem and how much risk we attach to it.

The exact point along the scale will be different for each of the above criteria and often difficult to measure. A useful way of assessing the risk may be to get some idea of the range of risk by combining all the most unfavourable estimates for each criterion to give an extreme pessimistic assessment of the problem. Conversely, the most favourable forecasts added up, provide the most optimistic view. Within this range is placed the assessment derived from the most probable estimates for each criterion. Defining the range of uncertainty in this way helps us to avoid expensive management errors. Additionally, societies will weigh these component criteria differently and thus arrive at a result more responsive to their own regional environmental needs.

Many environmental observations are mis-interpreted because of an ignorance of environmental processes. For example, allegations of oil pollution on some coasts may in part be due to a confusion between oil scum on the rocks and the black, universally distributed lichen *Verrucaria* which is naturally present in just this situation. Similarly, a concern over oil in the marine environment is largely justified because of its impact on seabirds and not because of any demonstrated adverse effect on aquatic life, and yet the universality of oil pollution in the sea is widely taken as a threat to marine ecosystems. Appreciation of the significance of such substances as lead, mercury, or sulphur dioxide in the environment must depend on an understanding of the natural levels and cycles of these materials. Very often the detection of an environmental contaminant may be a reflection of the quality of the analytical techniques. It may also be valuable for the insight it gives into an environmental process rather than proof of a local hazard. The discovery of DDT in penguin fat was an admirable illustration of this since it is well below the level at which any adverse effect can be expected and because it established the global transport of organochlorine residues.

In the assessment of whether a problem is real, it is necessary to know about the natural or background situation, the sources of the effect which is regarded as posing a problem, the natural corrective mechanisms that would operate if the perturbation ceased, the additional environmental systems that might be disturbed if the problem remained, the responses of the various components of the environment being affected, and the scale in space and time. There is a particular role for science in the assessment of the risks resulting from any action that changes the environment. For example, to make such an assessment for a chemical contaminant, it is necessary to know quantitatively the amount transported from the point of release to the receptor through physical pathways and food webs and the probability of effects in the receptor per unit dose. By multiplying this probability by the size of the population at risk, an estimate is obtained of the total resulting harm. Analogous processes can be used to assess the likelihood of risk from physical alterations in the environment.

The evaluation of the significance of a problem is greatly aided by the existence of a monitoring system. This may be physical or chemical, measuring pollutants or indicators of land use patterns, or biological, following the distributions or performance of 'indicator species' which by their changes may alert us to hitherto unsuspected factors. Many monitoring systems have not been well designed in the past and much more attention could usefully be given to the sampling pattern they adopt. For example, many of the world's monitoring systems take measurements at points chosen for convenience rather than because they provide a network that adequately samples the range of environmental variation or the range in the variation of human activities within the area under review. The spacing of sampling in time is also very frequently insufficiently considered. All monitoring schemes should sample without bias the variation in environmental phenomena using, if at all possible, the same basic sampling philosophy so that the results of environmental, chemical, and biological surveys can be interrelated. Too many monitoring systems consider single variables in isolation, whereas it is the establishment of correlation between variables and organisms that is often the most valuable in suggesting the existence of a problem and also in defining the rate of change in a trend. The most important function of monitoring for pollutants is to obtain data from which the doses received by critical receptors may be calculated.

The final issue in problem evaluation inevitably involves weighting, value judgment, and social responses. These must take account of the fact that a problem in one country may not be regarded as of sufficient severity to justify action in another. For example, in many parts of the world, new land is being developed for agriculture using methods which would be regarded as inappropriate in more affluent societies, yet the pattern will be largely determined by economics, and local administration may have difficulty in recognizing that the current practices, which may be all that their socio-economic systems can sustain, create problems. Very similarly, the value that is placed on wild life is socially determined, and the attitudes which prevail in Northern Europe and North America may seem quite inappropriate to developing countries with no tourist industry and an urgent need to open up the forest for grazing and cultivation. The word 'problem' is itself emotive: what we are really dealing with is choice and the need to inform that choice scientifically. The costs and benefits of alternative actions are rarely absolute: even the development of fertile land for agriculture has disbenefits, and the important thing is to draw up the balance sheet in as dispassionate a manner as possible.

Inherent in problem definition are such concepts as 'acceptable risks' and 'the use of the environment as a resource'. It must be emphasized that all human activities which impinge on the environment are likely in one way or another to alter the pattern of factors which in turn determine human survival and happiness. It would be unrealistic to expect that absolute safety could be the outcome of any human policy – but relative safety and maximal longevity remain an understandable goal! What is needed is a balancing of costs and benefits of individual actions including environmental protection policies, so that the maximum net benefit accrues. It must also be recognized that these points of balance will differ from country to country. For example, in developing countries with a mean expectation of life of only around 40 years in some social groups and low standards of housing, medicine, nutrition, and sanitation, the chief concern will obviously be to increase the quality of human settlement and the standard of living of the individual. Such a community may well be willing to accept as a consequence of full employment the generation of environmental contamination which may curtail life toward the end of the human span. If the result of industrial development is to raise the expectation of living from around 40 to around 60 years some chronic effects that are not manifest until the late 60's may be tolerable in a fashion that would not prevail in North America or Western Europe or indeed in the developing country itself once it had moved forward from the first phase. Similarly, countries with the urgent need to improve the standard of human life may embark on programmes of environmental development which cause consequential losses in wild life and natural beauty that would not be acceptable to developed countries.

There is clearly a dilemma in this situation which is essentially linked to time scales. Countries that have become developed cherish many of the features which tend to be disregarded and have low value put upon them in the early stages of development and regret with hindsight the losses that occurred early in the process. It is predictable that similar attitudes will emerge in developing countries that may be inclined initially to sacrifice some of the luxuries of environmental quality for the necessities of adequate health and employment. The timing of environment protection policies needs consideration in relation to the timing of development and the ways in which the acceptability of risk changes as communities develop and priority goals are attained.

Linked to this question and involving fundamental biological properties is the extent to which environmental change is reversible. For example, the contamination of a freshwater body whether by excessive nutrients or by toxic substances leads to changes in its flora and fauna. These are rarely completely reversible, if only because the nutrient status of lakes tends to change as they become filled by sediment and receive inputs from the surrounding catchment. The process of eutrophication can thus be natural, and its acceleration by man is unlikely to be wholly reversible. Processes of removal of natural forest or loss of soil are only reversible on a long time scale, if at all. On the other hand, there are many examples in developed countries of the restoration and rehabilitation of degraded ecological systems, for example by reafforestation and erosion control. All such processes involve a considerable management effort and there are no models which at the present time adequately express the relative costs of rehabilitation as opposed to the cost of prevention of damage in various situations. It may be desirable for these to be developed.

There is another divergence of view between those who believe that it is normally wrong to allow any avoidable waste material to be discharged into the environment or any avoidable environmental change to take place and those who believe that the capacity of the environment to take in waste products and render them harmless is a natural resource which it is legitimate to use but not to misuse to the point where degradation follows. On the latter view the logical course of action is to consider, for any piece of the environment, the amount of sewage or industrially toxic waste or land use transformation that is tolerable and allow this to be attained but not exceeded. There is a very close relationship between this concept and the concept of acceptable risk: so far as the use of the environment as a resource to take in pollutants and undergo transformations is concerned the concept is really linked to one of 'acceptable standards'. The no-change philosophy, on the other hand, takes the view that any modification in the environment from the natural condition may be in the direction of lowered productivity, diversity, and 'health' and should be resisted to the maximum extent feasible. Where air is currently clean it should therefore not be allowed to become dirty and where rivers run pure, they should not be allowed to receive discharges of toxic waste.

Clearly there are intermediate positions. Generally speaking, it is evidently desirable to reduce heavily polluting industrial emissions by installing modern equipment operating to a standard, even if there are still some residual emissions, and the movement of industry to areas where its net impact is significantly reduced may be acceptable. However, there is a genuine problem in determining the extent to which the philosophies of 'acceptable standard' and of 'no acceptable change' should be implemented. In judging whether or not an environmental activity constitutes a problem, it is necessary to consider which standpoint is being adopted. The better the scientific understanding of how pollutants and wastes are dispersed and degraded in the environment, the easier it will be to make such judgments with confidence.

D. INFORMATION AND COMMUNICATION PROBLEMS

In the mid-nineteenth century, an educated man could know almost everything worth knowing about the natural sciences. Today, a person must spend several years of study beyond a first degree before reaching the forefront of knowledge in a single discipline, or even a part of that discipline. In the twenty-first century, the specialist may be able to communicate effectively only with other scientists in the same speciality, and there is a danger that science may collapse through compartmentalization.

As the number of scientists, the range of techniques available to them, and the body of accumulated knowledge has expanded, there has been a parallel escalation in the output of professional publications. Over the past three centuries the number of journals and of individual papers has doubled about every 15 years and in 1971 there were about 35,000 journals producing 2 million articles by 750,000 scientists each year, in about 50 languages (Harrison Brown 1971). What are now termed the 'environmental sciences' encompass some ancient disciplines such as astronomy and geology and some of recent origin like ecology. Interdisciplinary themes such as pollution, natural resource planning, environmental modelling, and conservation have grown with them. Many such 'horizontal' groupings are inevitably heterogeneous and they have sometimes become separated from the older, basic, sciences on which they must nonetheless draw and which have themselves developed new specializations (such, for example, as molecular biology). Inefficiencies in communication are already manifest in science. They are likely to grow as the literature expands. It is more difficult for the individual to sort out the important information he should master from the 'noise' he should not even scan. For the specialist, in a narrow field, the problem is less difficult for his publication needs are being met by the creation of more and more journals, each having a narrower scope than the previous one. The situation is worse for the environmental generalist. Should he be content with wide-ranging reviews which depend on basic papers he may not be competent to evaluate? There are many abstracting journals and services, but here too the problem may be not only a capacity to evaluate the reliability of the work to which they may lead the user but the sheer volume of information they reveal. Faced with this, the environmental scientist may need to consider alternative systems for data collection, analysis, and presentation – for example linkages, via a referral system, to data sources. The output of the environmental scientist may likewise be a body of data, deposited in machine-readable form, to which attention is drawn by a short summary.

To members of the scientific community who need to evaluate authoritatively the scientific results of many different specializations and to interpret these to non-scientists, this 'knowledge explosion' poses new problems. This is one reason for Mid-term Project VII, which is concerned with communication. We must recognize that scientists themselves have been guilty of contributing to the inefficiency of the information system by the formats they have used for communication. The traditional scientific paper is not the most appropriate vehicle to bring scientific evaluations to policy-makers, and scientific advisors cannot expect judgments to be accepted if they are not expressed in a form suited to the user – or in a way that defines their likely margin of error. Sometimes they may require the interposition of a scientifically-trained 'translator' between the scientist undertaking the research and the policy-maker using his results.

PART II

The Mid-term Programme of SCOPE and the environmental activities of ICSU

CHAPTER 3

Environmental Concerns

A. INTRODUCTION

From the commencement of its work, SCOPE recognized that environmental issues could be classified in several ways:

(a) by sectors (e.g., air, land, sea, freshwaters);

(b) by biomes (e.g., tundra, forest, desert, grassland);

(c) by processes (e.g., pollution, desertification, competition); and

(d) by the nature of human response or approach to them (e.g., monitoring, modelling, standard setting, resource planning).

No single classification is appropriate to all circumstances. The choice usually depends on the purposes for which the information is assembled and analysed. For this part of the report, which presents detailed information about the activities in the Mid-term Programme of SCOPE and reviews the wider interests of the ICSU Unions, Commissions, and Committees, a two-way matrix (Figure 1) has been drawn up as an overall framework.

The present chapter on Environmental Concerns reports on the topics forming the first axis of the matrix: biogeochemical cycles (including the cycles of substances whose levels in the biosphere have been changed by man), pollutants, and ecosystems (and their response to interference). The reports on biogeochemical cycles emerge from Project I in SCOPE's Mid-term Programme, those on ecosystems from Project II, and those on pollutants from Project IV. In addition, a section on climate and its possible disturbance by man has been inserted because of the contemporary interest of the subject and its fundamental importance to biological processes. The boxes for 'non-renewable natural resources' and 'human ecology' are included in the matrix as an indication of the importance of those fields, but SCOPE has not undertaken specific studies that can be grouped here and no special section dealing with them has been prepared.

Part of Chapter 1 refers to the need for wise use of non-renewable resources such as fuels, soils, or agricultural land. By and large, the management of non-renewable resources is a matter of economics and book-keeping. It is important to conduct thorough surveys to define the scale of the resource and to evaluate the environmental and social implications of alternative patterns of resource use.

Concerns Responses	Climate	Biogeochemical Cycles	Pollutants	Ecosystems	Non-renewals Natural Resources	Human Ecology
Problem Identification and Monitoring						
Modelling						
Risk Estimation						
Evaluation and Communication						
Standard Setting Social Policy						

Figure 1 Matrix classification of environmental issues

Exploitation tends to concentrate on the cheapest available reserves of raw materials or energy. If demand is sustained or grows as rich sources are fully utilized and depleted, the value of poorer or substitute resources rises and their exploitation becomes economically viable. Ultimately, a disproportionate amount of effort, cost, and energy may be absorbed if a demand is to be met, but this in itself tends to apply economic brakes to further exploitation and provides an incentive for use of substitute materials, energy sources, or recycling. In the energy field, for example, projected exhaustion or inadequacy of fossil fuel reserves has stimulated nuclear power development, and worries over the attendant scientific, technical, and environmental problems (such as the disposal of plutonium wastes) have led in turn to proposals to pursue solar, geothermal, and other sources of energy. Probably the world's energy future will involve a variety of sources, in different proportions at different places and times. Rising costs and demands for high standards of safety and environmental quality will be likely to promote energy-conserving processes and reduced use. These matters extend beyond SCOPE's field, but there is a continuing role for the scientist in the estimation of reserves of resources (other ICSU bodies are concerned with aspects of this), and the analysis of the environmental implications of alternative systems of production and utilization. These topics are discussed further in Chapter 6.

Similarly, the present chapter does not contain a detailed report on human ecology, although the report on SCOPE Mid-term Project III on Environmental Aspects of Human Settlements, in Chapter 4, is relevant here. Population issues are discussed generally in Chapter 1, and the role of the scientific community in their study is referred to in Chapter 6. There are other gaps within the sections: noise, for example, although a pollutant causing increasing concern, has been the concern of IUPAP and there is nothing on food (including the development of new and unconventional food sources like those studied in the Use and Management section of IBP). All these could have been considered if resources had been available to SCOPE. Many, however, are the concern of WHO, FAO, and other ICSU committees or unions (see Chapter 5 and Appendix 3).

It is inevitable that many overlaps occur and that wide-ranging projects may fall partly under one heading and partly under another. The report on human settlements is one example: that on pollutants, which also provides information vital to risk estimation, is another. There are obvious affinities between the detailed study of the analysis and modelling of successional change in terrestrial vegetation included in this chapter and that on the general theme of simulation modelling (Project V in the SCOPE Mid-term Programme) in Chapter 4. Figure 1 should be used as a general guide to both chapters, and has relevance to the analysis of the environmental work of ICSU described in Chapter 5.

B. BIOGEOCHEMICAL CYCLES

1. Introduction

As Chapter 1 pointed out, human economic activities are now affecting all the main components of the biosphere. The atmosphere, hydrosphere, soil cover, and all living organisms are affected in a great variety of ways, and even the earth's crust is increasingly modified by mining, oil exploitation, and other operations. Some of these activities have a potential impact that has not been fully appreciated. For example, the complete deforestation of large areas and the extension of ploughing to additional tracts of natural grassland may lead to a decline in total world biomass as well as to the impoverishment of the flora and fauna in terms of species diversity. There are compensations through the reclamation and development of infertile lands, the irrigation of arid soils, and the development of increasingly productive agriculture in some places. However, these gains may be exceeded by losses in biomass or by soil deterioration and it is vitally important to measure the scale of the changes.

Modifications in the plant cover of the earth are associated with changes in global and local cycles of water which are observed in many parts of the world. Devegetation, and especially deforestation, alters the regimen of surface water and if not carefully controlled may lead to erosion as well as increased loss by evaporation. The construction of dams, canals, and irrigation schemes has altered the hydrology of the land in certain areas, intensified evaporation and has locally caused the mobilization and accumulation of salts in water and surface soil. Air pollution causes the acidification of rainfall in many areas. Mineral loading in river and lake water is, in general, increasing. The implications of these interacting changes in the water cycle need thorough evaluation.

The earth's surface is naturally a mosaic of different kinds of vegetation and fauna associated with different topographic and hydrological features. Man not only modified this initial heterogeneity but created a secondary mosaic of farms, water storage and supply systems, communication networks, towns, industries, nature reserves, national parks, and waste disposal areas. With this secondary heterogeneity are associated changes in the distribution of minerals which are mined in increasing quantities and used by industry to manufacture new compounds. The burning of fossil fuels, the ejection of dust and aerosols into the atmosphere, the extensive application of fertilizers and pesticidal sprays, and changes in cultivation systems have had a profound impact on the biogeochemical cycles of important substances and have added to the biosphere materials which were not naturally present there before the human industrial era.

A notable feature of the twentieth century is the accelerating progress of chemistry, discovering new elements and their isotopes, creating large numbers of new compounds, and disseminating the products of the chemical industry into all branches of human life. The increase in the chemical loading of the biosphere particularly affects the cycles of carbon, nitrogen, and phosphorus which are vital to the support of life. Cycles which have developed over millennia are now modified through many processes, e.g.:

(a) Increase in the nitrification of the environment.

(b) Enrichment of the environment with a wide range of carbon compounds.

(c) Increased ejection of sulphur compounds, especially into the atmosphere but returning to freshwaters in rain.

(d) The secondary acidification of the environment through sulphur and nitrogen emissions and the consequential decalcification, especially of poorly buffered water bodies.

(e) Increases in the phosphate levels of the land and freshwaters especially through fertilization but also through the increasing levels of phosphorus in treated sewage effluents.

(f) Widening contamination of areas of the environment with elements and compounds previously present only as traces. This may be a particularly significant process because the biological significance of many rare elements is not fully understood.

Reduction of soil cover is one of the more dangerous phenomena at present because the rates of production of new soils are so slow and many processes which created the existing soil cover (e.g., glaciation over much of the northern hemisphere) are not now widely operative and would themselves bring even greater disruption. Losses of soil resources, coupled with perturbations in hydrological cycles and variations in climate and in chemical contamination caused by urban and industrial processes, constitute a significant potential threat to human well-being. It is clear that natural biogeochemical processes are intimately interlinked with the effects of man's impact on the biosphere. Conversely, an understanding of biogeochemical cycles is of fundamental importance if man's impact is to be examined with a view to applying appropriate scales of regulation. This is why SCOPE, in its Mid-term Programme, attached great importance to the processes of biogeochemical cycling.

The following sections of this report describe in detail the cycles of nitrogen, phosphorus, sulphur, and carbon. In addition, SCOPE has been concerned with the way in which biogeochemical information can best be presented. The cartographic format is well suited to display information on regional patterns in the distribution of important elements; a sub-project on biogeochemical cartography was included. A workshop considered a provisional programme for geochemical cartography in which cartographic presentations would be used to show the interrelationship between biogeochemical processes and patterns at local, regional, and global scales, and the patterns of vegetation and plant productivity. In addition, the techniques would be valuable in presenting the results of monitoring background levels of biosphere elements and the distribution of materials released by man. It was suggested that the mapping of potential vegetation and the recording of modifications of existing vegetation should be undertaken alongside catalogues of the mineral composition of the more important dominant plants. This information could be related to maps of the distribution of elements, for example in stream sediments or in the soil and in annual mineral deposition and absorption. Mapping of the composition, quantities, and flow of dissolved materials would clearly be valuable in extending the process to inland waters. Mapping of the composition of rainfall would equally be important in determining inputs to the soil and vegetation and ultimately to the drainage systems.

Activities in many of these fields are in progress in a number of countries. A series of extensive biogeochemical maps has been prepared for the Soviet Union, and the composition of the sediments in stream beds has been analysed in England, Wales, and parts of Scotland. There are extensive vegetation maps, including potential vegetation, of large areas of North America.

2. Nitrogen, Phosphorus, and Sulphur

a. *Man and Biogeochemical Cycles: Impacts and Problems*

Nitrogen, phosphorus, and sulphur are essential elements in all living matter and are found in varying proportions to carbon, depending on the chemical nature of the compounds in which they occur. A pattern for the circulation of these elements in nature developed when microorganisms, plants, and animals appeared on earth. The pattern was set by the physical and chemical environment, by the chemical nature of these elements, and by the geographic distribution of microorganisms, plants, and animals. The appearance of *Homo sapiens* may not have had any great effect on these patterns as long as man was nomadic. That state of affairs changed when man formed settlements to which he transported vegetable matter and meat, but from which hardly any waste returned to the source areas. The effect must have been particularly noticeable for phosphorus which is scarcely leached from soils and this accumulated in the soils of the settlements and their immediate surroundings. Analysis of soil phosphate has been used in Sweden to locate archaeological settlements. It is, of course, difficult to assess the impact of such a process on the environment. Man continues to perturb the natural biogeochemical cycle today, with the difference that in some settlements a great deal of the accreted phosphorus is released into lakes and rivers. In some regions agriculture has been practised for a very long time and must have led to a sizeable depletion of phosphorus in soils; one reason for the present use of phosphorus fertilizers. The intensive cropping of small areas of woodland in Eastern England over many centuries for firewood, wattle, and building timber has led to a depletion of phosphorus levels in those soils.

Similar processes must also have occurred for nitrogen and sulphur, although their chemistry would favour leaching from soils or return to the atmosphere. Nitrophilous plants such as nettle (*Urtica dioica*) are characteristic of ground disturbed and enriched by man in some temperate areas. In arid areas, archaeological sites sometimes show accumulation of nitrate in and around former sewage dumps – as observed, for example, in prehistoric settlements in the Indus valley. Arid conditions would also lead to high nitrate concentrations in ground waters formed in settlement areas. The high nitrate concentrations observed in ground waters in the semi-arid parts of India and Africa are perhaps partly due to such human intervention in biogeochemical cycles in the past.

Man's control of plants capable of fixing atmospheric nitrogen may constitute another source of interference in the nitrogen cycle. Such control may have been exercised even before the discovery of nitrogen-fixing organisms via changing food habits and, inadvertently, by the grazing of domestic herds in virgin areas.

In order to assess man's impact on the biogeochemical cycles of nitrogen, phosphorus, and sulphur, it is necessary to define a reference state for these cycles. In view of the foregoing discussion, this may not be so simple. The most we can do – and it is clearly unsatisfactory – is to assess the impact of man's activity on these natural cycles during the last century as compared with the preindustrial state rather than with the much earlier natural state. It is possible that some of the more recent impacts of man may have been amplified by 'ancient' impacts.

A breakthrough in modern agriculture came with the invention of industrial processes for fixing atmospheric nitrogen. An almost unlimited reserve of nitrogen fertilizers is foreseen, although production may be limited by available energy. The fate of the fixed nitrogen has only recently been studied quantitatively. Denitrification returns nitrogen to the atmosphere as either nitrous oxide or molecular nitrogen. Atmospheric nitrogen oxides formed from nitrous oxide seem to be involved in the destruction of ozone in the stratosphere. It has been suggested that an increase in the production of nitrous oxide in soils could affect the ozone layer which shields the earth from solar ultraviolet radiation. Locally and regionally, excess nitrate in water increases eutrophication. Similar to phosphorus, nitrate concentrations in ground-water supplies may increase to levels above those recommended as safe by WHO.

The impact of man's activity during the last century has been spectacular in many respects. Through mining, phosphorus has become easily available, enriching food and wastes. Through modern sewerage, a large part of this is conveyed into river courses, changing their ecology. Although, unlike nitrate, phosphorus is practically immobilized in soils, bad farming practices can increase soil erosion, thereby adding more phosphorus to streams. There is the concomitant threat of eutrophication of inland and coastal waters in some regions, plus the fear of depletion of mineable phosphate reserves, critical to world food supplies.

The growth of modern industry increased demands for readily available energy, so far mostly supplied by fossil fuels. The latter contain sulphur, which, on combustion, is released into the atmosphere as sulphur dioxide and then partly deposited as sulphuric acid. The result is an accelerated rate of land denudation and changes in freshwater ecology in regions with hard rocks and numerous lakes. Up to now this problem appears to have been limited to certain regions, but with intensified industry it may become widespread. Sulphur emissions also increase rates of corrosion and are a health hazard in some areas.

Problems such as those mentioned above might be resolved by better knowledge of the biogeochemical cycles of nitrogen, phosphorus, and sulphur. It is difficult to see how best to improve the environment without first establishing fundamental facts: such facts will also serve to offset the interminable speculation frequently passing for knowledge. The summary given in the following sections is based on SCOPE 7 (Svensson and Soderlund 1976).

b. Flow Charts for Nitrogen, Phosphorus, and Sulphur

As a first objective, an attempt has been made to obtain global estimates of the amounts of the three elements stored in various 'reservoirs' or compartments in nature and of the fluxes of these elements between the different compartments. The division of nature into compartments is arbitrary to some extent. The number of compartments chosen for such a model of nature depends both on the geographical scale of the process under consideration and on the state of knowledge of the process. These inventories and flow charts are presented and discussed in the following sub-sections of this report.

In the flow charts for phosphorus and sulphur (Figures 3 and 4), the preindustrial states are represented by estimated figures of fluxes and storages. The effect of present (1970) human activity is then indicated by figures added to the preindustrial ones, the total yielding the present state.

The flow charts can be regarded as crude compartment models. The dynamic behaviour of the models is, however, not discussed. This is a subject for future studies. Some comments on this subject may, nevertheless, be useful. In the past, very simple approaches were often made implying a dynamic response of a compartment to be linear and of the first order, which meant that the flux from the compartment is directly proportional to the storage alone. Under such circumstances, the response is determined by one parameter, the turnover time, which is obtained by dividing the storage of a compartment by the steady flux from it. However, most compartments in nature do not behave so simply. Taking organic matter in podsolic soils as an example, the turnover time is of the order of 100 years whereas the average age, based on carbon-14, is of the order of 1,000 years. From this it is obvious that a major fraction of organic matter added to these soils is converted into carbon dioxide in a few years time, while a small fraction becomes so resistant that it takes many centuries before it is converted to carbon dioxide; this fraction therefore constitutes the major fraction of organic matter in these soils. This is also true of the oceans and the atmosphere, respectively taken as single compartments. The dynamic features of such compartments are properly described by distributions of transit times. The dynamic features must be taken into account for predictions of future states of biogeochemical cycles.

In the construction of a flow chart, balancing of preindustrial fluxes is sometimes resorted to for computing some of the fluxes. This implies that the chart represents means in stationary states, where limited fluctuations are permitted. Flux balancing is, however, questionable for compartments having large turnover times, and fluxes obtained by balancing convey no new information.

Global flow charts integrate the effects of man's activity over the earth's surface. Since there are large regional differences in that activity and the turnover times of the substances in air are often small, the global flow charts do not give a fair picture of the impact. On the other hand, regional cycles are usually impossible to assess on the basis of present-day knowledge. Part of a cycle can, in rare instances, be outlined quantitatively – as will be seen when discussing the sulphur cycle. Such regional cycles will more clearly show the effect of man's activities.

There are important couplings between the cycles of nitrogen, phophorus, and sulphur as well as with other elements, especially carbon. These have, however, not been considered in any detail in the present report and some are examined in a separate report (Kovda 1975). There are close bonds to other SCOPE Mid-term Projects, especially I.1 (Carbon and oxygen cycling), I.4 (Biogeochemical cartography), V (Simulation modelling), and VI (Environmental monitoring).

c. *Nitrogen Flow Chart and Comments*

The flow chart presented in Figure 2 is more complex than those for phosphorus and sulphur (Figures 3 and 4) in that the form of nitrogen has been specified. On the other hand, the number of boxes has been reduced. It gives only the net fluxes between the pedosphere, hydrosphere, and atmosphere, and the flows represent 1970. In many instances there are flows of the same compound both to and from the same box, i.e., nitrogen added through fixation and lost through denitrification. This is represented by a closed loop. Nitrous oxide (N_2O) is included in the figures for nitrogen (N_2) in the fluxes from the pedosphere and hydrosphere to the atmosphere (denitrification). The internal transformations in soils and waters between organic-N, ammonium-N, nitrite-N, and nitrate-N are not considered in the present chart. It should be noted that the internal circulation of nitrogen is much larger than the fluxes between the three boxes in Figure 2 (Soderlund and Svensson 1976). The global inventory of nitrogen is given in Table 1.

Nitrogen fixation. The rates of terrestrial nitrogen fixation are taken from Burns and Hardy (1975), giving 139 Tg per year. This is considered as a possible lower limit for the biological fixation. To this amount is added the industrial nitrogen fixation (36 Tg in 1970; UN 1975). An additional amount is fixed through combustion and liberated as NO_x (19 Tg). The value for nitrogen fixation in the aquatic environment is estimated, based on data from Gundersen and Hanson (unpublished), to be 15–80 Tg per year for tropical waters. The fixation rate for temperate waters is not known accurately and is assumed to be 25 percent of that in tropical waters. The total fixation is thus set as 30 to 130 Tg per year for the aquatic habitats including sediments.

Denitrification. Gaseous nitrogen and nitrous oxide are formed by nitrate reduction in anaerobic environments, thus being removed from the system. This can be an important negative effect after fertilizer application in agriculture and forestry, but it can be considered positive when it occurs in sewage treatment plants. Little is known about the quantities of nitrogen and nitrous oxide formed on a global scale. Hahn (1974) estimated the annual N_2O production from the ocean to be 20 to 80 Tg. An additional 16 to 69 Tg of N_2O should be released from the terrestrial habitats. The total amount of nitrogen lost from the pedosphere is given as 108 to 160 Tg (Figure 2), assuming that the pedosphere and hydrosphere are in a steady state. The total inputs and outputs from these boxes are balanced by setting the limits for denitrification. N_2O is transported to the stratosphere at a rate

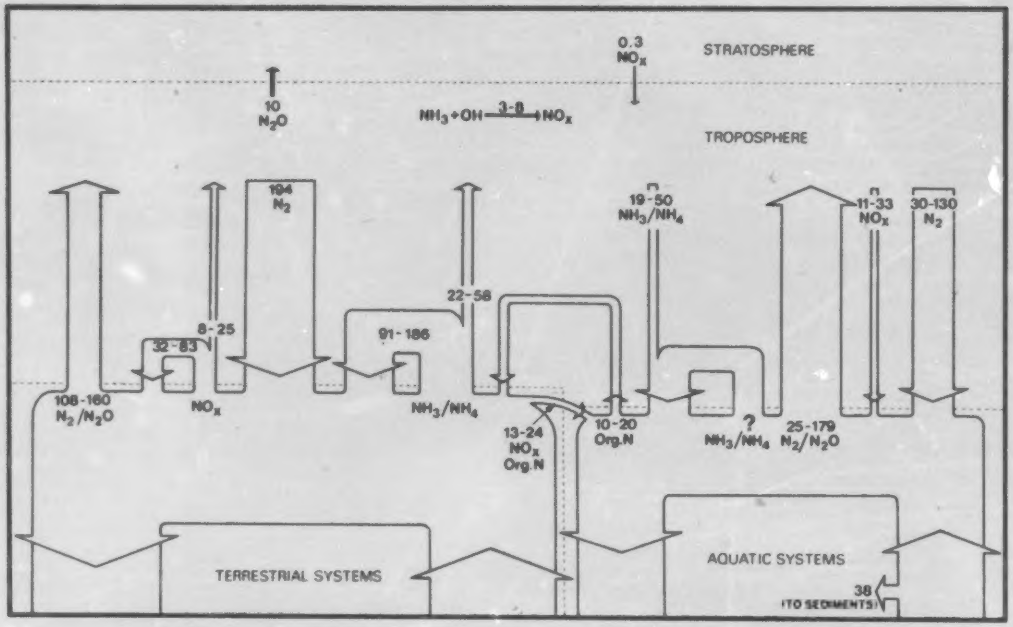

Figure 2 The global nitrogen cycle. The rates are given as Tg N yr^{-1}. The flows of N$_2$/N$_2$O are residuals obtained when balancing the terrestrial and aquatic systems (Soderlund and Svensson 1976)

TABLE 1 Global Inventories of Nitrogen in the Terrestrial, Oceanic, and Atmospheric Systems (Tg N) (Schultz, K., Junge, C., Beck. R., and Albright, B. 1970)

System	Reference	Amount
TERRESTRIAL		
Plant biomass	Soderlund and Svensson (1976)	$1.1-1.4 \cdot 10^4$
Animal biomass	Delwiche (1970)	$2 \cdot 10^2$
Litter	Soderlund and Svensson (1976)	$1.9-3.3 \cdot 10^3$
Soil		
Organic matter	Soderlund and Svensson (1976)	$3.0 \cdot 10^5$
Insoluble inorganic	Soderlund and Svensson (1976)	$1.6 \cdot 10^4$
Microorganisms	Soderlund and Svensson (1976)	$5 \cdot 10^2$ [a]
Rocks	Stevenson (1965)	$1.9 \cdot 10^{11}$
Sediments	Stevenson (1965)	$4 \cdot 10^8$
Coal deposits	Donald (1960)	$1.2 \cdot 10^5$
OCEANIC		
Plant biomass	Soderlund and Svensson (1976)	$3.0 \cdot 10^2$
Animal biomass	Delwiche (1970)	$1.7 \cdot 10^2$
Dead organic matter		
Dissolved	Soderlund and Svensson (1976)	$5.3 \cdot 10^5$
Particulate	Soderlund and Svensson (1976)	$0.3-2.4 \cdot 10^4$
N_2 (dissolved)	Delwiche (1970)	$2.2 \cdot 10^7$
N_2O	Soderlund and Svensson (1976)	$2.0 \cdot 10^2$
NO_3^-	Emery et al. (1955)	$5.7 \cdot 10^5$
NO_2^-	Soderlund and Svensson (1976)	$5.0 \cdot 10^2$
NH_4^+	Soderlund and Svensson (1976)	$7.0 \cdot 10^3$
ATMOSPHERIC		
N_2	Robinson and Robbins (1970)	$3.9 \cdot 10^9$
N_2O	Schütz et al. (1970)	$1.3 \cdot 10^3$
NH_3	Soderlund and Svensson (1976)	0.9
NH_4^+	Soderlund and Svensson (1976)	1.8
NO_x	Soderlund and Svensson (1976)	1–4
NO_3^-	Soderlund and Svensson (1976)	0.5
Org. N	Soderlund and Svensson (1976)	1

[a] This amount is inevitably included in the figure for organic nitrogen in the soil.

of 10 Tg per year. This N_2O is converted to N_2 (80 percent) and NOx and there are at present no indications of N_2O accumulation in the stratosphere.

NO_x-production. NO_x (NO and NO_2) is formed during combustion, and this anthropogenic source was estimated by Robinson and Robbins (1970) to be 16 Tg in 1965 (there has probably been an annual increase of 4 percent since), but this value is probably too low. It has also been reported that NO_x is liberated from soils (Kim 1973) and a rough estimate for a possible global production gives 1 to 74 Tg. NO_x wet and dry deposition over oceans (mainly in the form of NO_3^-) is estimated

to be 11 to 33 Tg, and it is assumed that this amount was formed over land. NO_x is further transported from the stratosphere to the troposphere at a rate of 0.3 Tg per year.

Ammonia. The amount of ammonia liberated from the pedosphere is calculated using data for nitrogen as urea in animal faeces. It is estimated that 5 to 10 percent of the urea produced is lost to the atmosphere, but this might, especially in regions with high pH or intensive cattle farming, be much higher. Of the total amounts (26 to 53 Tg), 2 to 6 originates from wild animals, 20 to 35 from domestic animals and man, and an additional 4 to 12 from the burning of coal. The liberation of ammonia is highly variable on a regional scale as is the adsorption of ammonia from the atmosphere by plants and soil. Liberation and adsorption of ammonia are mainly dependent on soil pH; this is indicated by maps of ammonia in rainfall over the USA (Junge 1958). The ammonia/ammonium in rainfall is estimated at 20 to 80 Tg, and this gives a total net flux from the pedosphere to the atmosphere of 15 to 40 Tg per year. Ammonia deposition over the oceans is estimated at 15 to 60 Tg, and, in order to balance this, the ammonium flux to the atmosphere from the pedosphere is set at 113 to 244 Tg.

River runoff. The total amount of nitrogen transported from the pedosphere to the hydrosphere by river runoff is calculated from data given by Ahl and Oden (1972) as 13 to 24 Tg. Better data for river runoff for nitrogen and phosphorus will be available as a result of the UNESCO inventory 'world register of rivers discharging into the oceans'.

d. Implications of Man's Activity for the Nitrogen Cycle

Global impact. The industrial fixation of atmospheric nitrogen is substantial. A part of the nitrogen thus added to soil will, through denitrification, be lost to the atmosphere. From the data given above, 15 to 40 percent of this nitrogen will be in the form of nitrous oxide (N_2O). A source of major concern in this context is the possible increase in stratospheric N_2O, which will cause a decrease in atmospheric ozone. The calculated effect is that a 1 percent increase in nitrous oxide causes a 0.2 percent decrease in ozone (Crutzen 1974). Man has also increased the biological nitrogen fixation through the cultivation of leguminous crops. The impact of increased biological nitrogen fixation is not known.

Regional impacts. In regions with intensive agriculture, heavy use of commercial fertilizers may lead to an increased leaching of nitrogen, especially nitrate, from the soil to water courses, and this will have regional and local effects.

Fixation of atmospheric nitrogen takes place during combustion processes, releasing mainly NO_x into the atmosphere. Nitric acid is then formed and deposited on the ground. In industrially developed regions this adds to the acidification problem of soils and freshwater systems unless denitrification occurs. This acidification may be partly counteracted by fertiliser application of fixed nitrogen as nitrate, since an equivalent amount of alkalinity results from denitrification and the escape of nitrogen or nitrous oxide

NO_x is toxic in high concentrations and is the main component of photochemical processes causing smog.

Local impacts. Nitrogen compounds leached from soils can contribute to eutrophication in fresh and brackish water systems. Changes in agricultural and silvicultural practices, such as intensified tilling and clear-cutting of forests, can mobilize nitrates through increased decomposition of organic matter.

Increased nitrate concentrations in ground water and waters used for human consumption can lead to health hazards. The nitrate concentration in crops also rises after heavy fertilization. Nitrate can be converted to nitrite, causing methaemoglobinemia, or to nitrosamine which is carcinogenic, but the scale of these problems needs further study.

e. The Nitrogen Cycle: Trends

The use of nitrogen fertilizers promises to increase. It has been estimated that there will be a 25 percent increase in Sweden over the next ten years (Kumm 1976). An upper limit for global use of nitrogen fertilizers was estimated as approximately 300 Tg per year. It is, however, possible that increasing energy prices will put constraints on the upper possible limit for nitrogen fertilizers. It is also possible that biological nitrogen fixation will increase considerably in the future as a result of the use of efficient non-symbiotic associations, the increased use of symbiotic associations, and the possibilities for genetical transfer of nitrogen-fixing ability to non-fixing plant species. Increased biological nitrogen fixation on a local scale could have the same impact as commercial fertilizers.

A substantial increase in the use of high altitude aeroplanes (for example, supersonic airliners) causing additional production of NO_x in the atmosphere would have an effect on the protective ozone layer.

f. Phosphorus: Flow Chart and Comments

The main features of the global biogeochemical cycle of phosphorus are illustrated in Figure 3 (based on Pierrou 1976). Some of the fluxes are labelled for easy reference. Amounts in the compartments are set within frames.

Atmosphere. The amount of atmospheric phosphorus is given as much less than 3 Tg.

Ocean surface water. This is the surface layer of the oceans down to about 100 meters depth, which is the approximate depth of the thermocline. This compartment contains the so-called euphotic zone. The average phosphorus concentration given is probably correct within ±0.1 Tg.

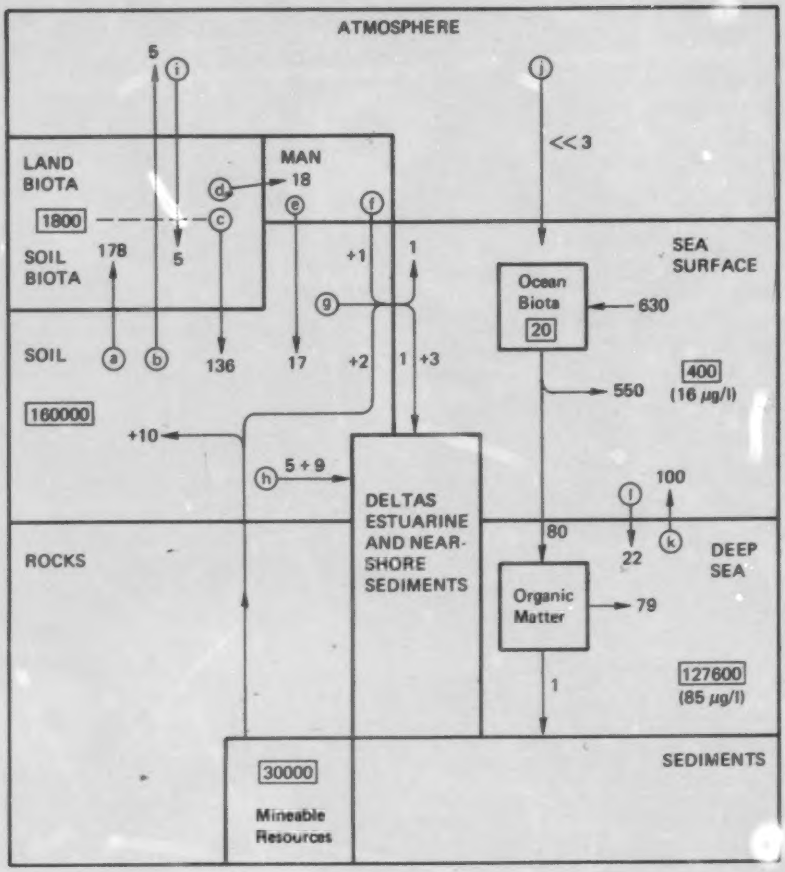

Figure 3 Preliminary global phosphorus flow chart. The units are Tg (million metric tons) per year (based on Pierrou 1976)

Deep sea. This is the remainder of the oceans with a volume of about 60 times that of the surface water compartment. The average phosphorus concentration is probably correct within ±13 Tg. The fluxes *k* and *l* are caused by the rate of exchange of water between the two compartments, using a turnover time for the deep sea compartment of 1,200 years, consistent with the carbon-14 distribution in the oceans. The water exchange causes a net transport of dissolved phosphorus from the deep sea compartment to the surface water compartment, largely balanced by the phosphorus in sinking particulate matter. This particulate phosphorus is released by decomposition in the deep sea compartment. The same internal cycle in the oceans is also found for carbon, nitrogen, calcium, and silicon. For sulphur it is masked by the high concentration of sulphate in sea-water.

Soil. This is taken to represent surface deposits on land down to about 1 meter depth, a possible average depth of the root zone. The storage is computed from an average phosphorus abundance of 0.11 percent by weight and a bulk density of 1 metric ton per cubic meter. A great deal of the storage is not readily available to plants although species differ considerably in their ability to take up phosphorus from soils. The storage is probably correct within ±50 percent.

Five Tg are transferred from soil to the atmosphere in dust. The figure is rather uncertain. Little of this is assumed to be carried into the sea and added to sea spray to form flux *j*. Some leaching of phosphorus from soils as dissolved phosphate seems to take place, ending up in the sea (flux *g*). This amount is fairly small. It corresponds to a mean river-water concentration of 30 micrograms per liter. A far greater loss of phosphorus from soils takes place through erosion (flux *h*). The figure is derived from a 'natural' denudation rate of 1 meter per 35,000 years, estimated from sedimentation rates in inland basins. Since the present denudation rate is about 3 times the natural, the addition of 8 Tg corresponds to a human effect. Most of the particulate phosphorus will end up in deltas, estuaries, and near-shore sediments, for which a separate compartment is shown. Phosphate mining at present amounts to 13 Tg per year of which 11 Tg is applied to agricultural soils. The rest is used industrially and domestically, mostly ending up in rivers. A special compartment, mineable resources, is given a storage of 30,000 Tg, using those phosphate ores containing 5 percent phosphorus or more. If a lower percentage is used, resources increase considerably.

Land and soil biota. This consists of phosphorus in vegetation and animals. The storage is from Woodwell and Pecan (1973). The reliability of this estimate is unknown. It is based on a plant biomass of 1.8×10^6 Tg (dry weight) and a phosphorus content of 0.1 percent.

As to the fluxes, the plant uptake, *a*, is taken from Bazilevich (1974), and is the part of the decay that is handled by man. A greater part is brought back to soil (flux *e*) while *f* is addition of phosphorus from human excreta to rivers. The amount is taken to represent a human effect, since waste release into fresh water is a departure from older practices.

g. *Phosphorus: Implications of Man's Activity*

Global. The internal circulation and the large storage of phosphorus in the sea can absorb fairly large additions without any noticeable effect.

Regional. On regional scales, the effects of man on the phosphorus cycle would be limited to aquatic systems on land and along coasts. Of particular interest are regions with an abundance of freshwater lakes having considerable water supply and recreational value. It is well known that eutrophication can occur by the addition of phosphorus from municipal sewage and from agricultural land. This is, however, mostly a local problem.

In coastal areas eutrophication may occur by addition of phosphorus to bays where exchange of water with the open sea is impeded. The effect also depends on freshwater inflows to bays causing estuarine circulation patterns which tend to accumulate phosphorus naturally. Such bays or even inland seas, such as the Baltic, have a tendency to develop anoxic conditions in deeper water because of stable density stratification and oxygen depletion by sinking particulate organic matter. In such cases even moderate additions of phosphorus from land can increase the anoxic conditions.

h. Phosphorus: Future Trends

The amounts of mineable phosphate reserves are dependent on the grade of the ore and will be reflected in the price the consumers are willing to pay for the phosphorus. Estimates of the world-wide reserves must take this into account. It is possible to estimate probable upper limits for phosphate fertilizer use, attainable only under the extreme conditions of scarcity of food and low fertilizer production costs relative to food prices. Such estimates do not represent forecasts. Under the conditions stated, the rate of phosphate fertilizer addition on a global scale could reach 50 Tg per year, or four times the present rate. If marginal pasture land is also taken into account an additional 20 Tg can be added.

A rate of 50 Tg per year is, of course, considerable in relation to present uptake by plants. It would of necessity increase the uptake somewhat, although a major part would add to the soil storage. Erosion rates would probably increase so that losses of phosphorus would also increase.

Regional effects of such an increase in fertilizer use would be inevitable.

i. Sulphur: Flow Chart and Comments

In recent decades many attempts have been made to describe the circulation of sulphur in nature in a consistent way, particularly with regard to the flux through the atmosphere. The circulation and transformation of sulphur in nature is still inadequately known and much uncertainty exists with regard to the mechanism and importance of processes involved.

It should be stressed that man-made sulphur emissions are confined to rather limited regions of the earth's surface. Since the residence time in the atmosphere of most of this sulphur is only a few days, the impact on the environment of this pollution constitutes a regional problem (scales of a few thousand kilometers). For most impact studies, regional budgets would therefore be more relevant than global budgets. As an example, a budget for the atmosphere over Northwest Europe is presented in Table 2.

On the other hand, the potential use of global budgets is to assess man's possible contribution to the global concentration of aerosols which may be of importance for the global radiation balance. Two examples of a global sulphur budget are presented (Figures 4 and 5). The first is based on an estimate of a preindustrial balance between sources and sinks for the soil, providing some indirect evidence of

TABLE 2 Sulphur Budget for NW Europe (Tg S/yr) (based on Rodhe 1976)

	Pollution Sulphur	Non-pollution Sulphur	Total
Emissions	13	?	13 + ?
Deposition			
By precipitation	4.1	0.5	4.6
By direct uptake	2.9–5.9	0.2–0.3	3.1–6.2
Total	7.0–10.0	0.7–0.8	7.7–10.8
Net export of pollution sulphur	3.0–6.0		
Net export as percentage of emissions	23–46		

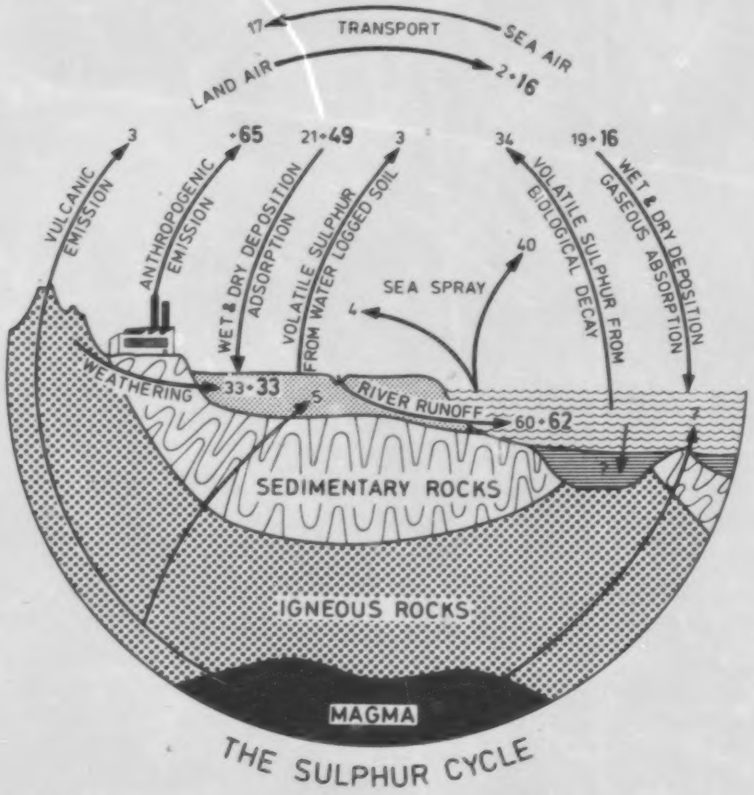

Figure 4 The first global sulphur cycle, based on a preindustrial balance of the soil compartment. Fluxes are given in Tg (millions of tonnes) of sulphur per year. The man-made parts of the fluxes are indicated by plus signs (Hallberg 1976)

the quantities involved in the atmospheric budget. The second budget is based directly on atmospheric chemistry information, in particular rainwater analyses.

j. Sulphur: First Global Budget

This global sulphur budget (Figure 4) is based on the assumption that there was a preindustrial balance between sources and sinks for the soil (Hallberg 1976). The flux of non-pollutant sulphur through the atmosphere is estimated to balance the estimated preindustrial river runoff.

River runoff. Eriksson (1960) estimated the total annual river runoff of sulphur at the turn of the century to be 75 Tg per year. According to Robinson and Robbins (1968) man-made sulphur emissions increased by 12 Tg from 1850 to 1900. Hence, 15 Tg (including contributions from mining and agriculture) is deducted from Eriksson's value to make the preindustrial runoff 60 Tg.

Reduced sulphur compounds from land. Sulphur derived from decomposing plant tissues may enter the atmosphere, and extrapolation of available emission data (Hitchcock 1976) indicates that this source amounts to only 2 to 5 Tg per year. Most of it is probably deposited on land. In the flow chart 2 Tg are assumed to be deposited on land and 1 Tg in the oceans.

Volcanic sulphur. Following earlier estimates, the contribution to the atmosphere is taken as 3 Tg and that to the soil as 5 Tg. Of the atmospheric part, 2 Tg are assumed to be deposited on land.

Sea spray. Eriksson (1960) estimated the production of sea-spray sulphur to be 44 Tg of which 10 percent is precipitated on land.

Weathering. The best estimates for preindustrial conditions are those based on denudation rates (Eriksson 1960, Judson 1968). However, weathering of the continental crust is not equal for igneous and sedimentary rocks because of their different resistance to weathering and their different areal distribution. According to Conway (1943) only 0.2 of the weathered continental crust comes from igneous rocks. The sulphur content of the average weathered rock is 0.33 percent which gives a mean annual value of 33 Tg for preindustrial weathering of sulphur.

Volatile reduced sulphur compounds from marshes, estuaries, and ocean. The emission of dimethyl sulphide from the ocean to the atmosphere has recently been studied but the measurements are still too inconclusive to warrant an estimate of the magnitude of this flux to the atmosphere. Biological decay under anaerobic conditions results in production of hydrogen sulphide whenever sulphate is present. Such environments, created by sulphate-reducing bacteria, are very common in tidal marshes and estuarine areas. They are also common in oceanic sediments except in the uppermost part which is usually oxidized. Because of the very short residence time (a few hours) for hydrogen sulphide in oxygenated waters it is unlikely that it escapes from deep water sediments to the atmosphere. The most probable process is release of hydrogen sulphide or other volatile reduced sulphur compounds from mud cracks in the intertidal zone. Measurements of sulphate removed from tidal waters flushing a marsh on the North Shore of Long Island, New York (Woodwell 1976) showed that if only a few percent of this is released in the form of volatile sulphur compounds into the atmosphere, the amounts would be sufficient to balance the preindustrial soil compartment. Thus the total flux of volatile reduced sulphur compounds into the atmosphere from coastal areas of the oceans is estimated in the following way. The preindustrial balance of the soil requires an atmospheric addition of 25 Tg. Four of these come from sea spray and another 4 from volcanic and biological sources on land. The remaining 17 Tg are assumed to originate from the previously discussed source. Assuming that 50 percent of the coastal emission is deposited on land, a flux of reduced sulphur from the coastal areas of the oceans is estimated to be 34 Tg.

Deposition on land and ocean. These figures (21 on land and 19 on the ocean) are obtained indirectly in order to balance the atmospheric compartment. It may be assumed that roughly 50 percent of the deposition is by precipitation and 50 percent by dry deposition.

Man-made contributions. Man has influenced the magnitude of several of the fluxes (Figure 4). These numbers are indicated in the diagram by a plus sign.

Fossil fuel combustion. According to Friend (1973), the annual sulphur emission to the atmosphere around 1965 was 65 Tg: 75 percent of this is assumed to be deposited on land.

Impact on weathering. Berner (1971) concluded that sulphur from rock weathering constitutes 35 percent of the total dissoved sulphur in the world average of river water. Based on Livingstone's data (1963), this corresponds to 42 Tg. Using 0.33 percent for the sulphur concentration of the average weathered rock and Judson's (1968) figure for world-wide river gauging, we obtain a figure of 105 Tg. The true value may lie between these and a figure of 66 Tg is chosen. Compared to the preindustrial figure this means that man has doubled the weathering rate.

Impact on sulphate reduction in marshlands. The limiting source for bacterial production of hydrogen sulphide is the supply of decomposable organic matter. In many coastal areas man has increased this supply and hence affected the production of hydrogen sulphide. No data exist.

Present river runoff. Livingstone's data (1963) for total annual runoff of sulphur is 122 Tg. As some of the data he used are from the end of last century or from the beginning of the present, the present runoff may be expected to be higher.

However, there is no need to balance the present state of the soil compartment. The soil storage may be changing at present.

Storages. In the soils of humid areas practically all sulphur stored is bound in organic matter. The semi-arid or arid areas soils and subsoils contain from 1 to 3 percent to as much as 15 to 60 percent of inorganic sulphates. The human impact on the cycle is fairly large when comparing preindustrial and present fluxes. Yet it is probably fairly small with respect to storages, except for the atmosphere.

k. Sulphur: Second Global Budget

The second budget (Figure 5) is based primarily on rainwater analysis (Granat 1976). A critical examination of available data especially in the light of recent quantitative knowledge about long distance transport of anthropogenic emissions, gives a rather different picture compared to what has hitherto been accepted (Friend 1973). A key question is, as before, the magnitude of the natural production of reduced sulphur compounds, as this is considered to be of particular relevance for the formation of aerosols in a size range that may interfere with visible radiation. Sea spray formation and suspension of soil dust are also considered in the budget scheme inasmuch as a small fraction of this material may be found in the size range below about 0.8 μm.

It must be noted that present information about processes and magnitude of fluxes in the natural sulphur cycle is insufficient for even approximate estimates. The uncertainty in the estimates is therefore probably not less than a factor 2 at the very best, except for that of man-made emissions.

Deposition with precipitation (wet deposition) is estimated from rainwater analysis in areas not affected by long distance transport of anthropogenic emissions as well as from an estimate of the possible natural contribution in Europe. It is estimated to be 18 Tg sulphur per year for land areas and 11 Tg sulphur per year for the ocean. These are considerably lower values than previous estimates. They do not include that portion of the sea spray which is in the form of particles larger than about 1 μm and which is removed by precipitation. In addition there is some 30 Tg sulphur per year emanating from man-made emissions deposited by precipitation.

Estimation of dry deposition of sulphur compounds from natural sources involves consideration of both reaction rates and pathways in the oxidation of H_2S, DMS, and other reduced sulphur compounds. A value of 0.1s g S m^{-2} yr^{-1} is adopted in this budget, based on the limited and to some extent contradictory information available. If dry and wet deposition over land and sea is compared with the contributions from volcanoes (3 Tg S), decay processes on land (5), and sulphur from sea spray in submicron particles (3), there is a deficit of some 27 Tg sulphur per year. This may be explained in two ways. The wet deposition may be overestimated due either to contamination during sampling or to unrepresentative sampling points. Alternatively, the production rates of gaseous sulphur compounds may be underestimated. The second alternative is considered

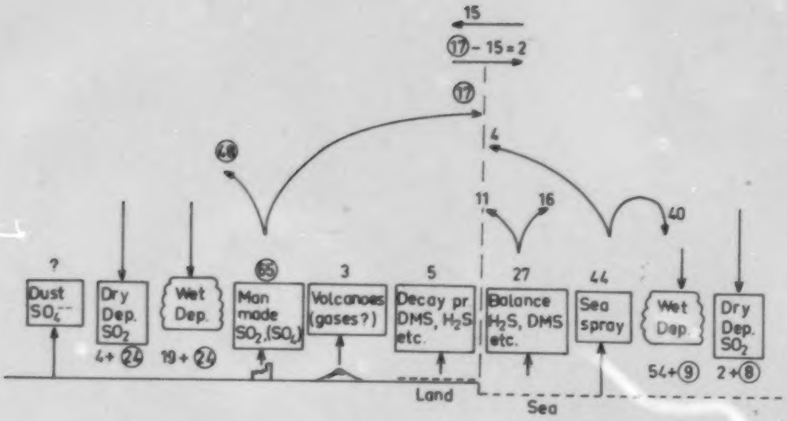

Figure 5 The second global atmospheric sulphur cycle, showing major source and sink mechanisms over land and sea. The fluxes emanating from anthropogenic emissions are encircled. The 'balance' flux, i.e., emission of reduced sulphur compounds that cannot be estimated directly may also take place over land areas (Granat, Rodhe, and Hallberg 1976)

the most likely. Possible source areas are tidal flats or other salt shallow waters and some additional production on land.

According to investigations over Europe the global man-made emission of 65 Tg sulphur per year can be removed equally by dry and wet deposition processes. About 0.70 of this will be deposited over land, the remainder over the oceans.

The tropospheric storage can be calculated from the production rate of submicron particles if the average residence time is known. A value of 5 days is adopted, giving a content of about 0.3 Tg sulphur in the troposphere. This can be compared with the storage of S in submicron particles due to man-made emissions which is estimated to 0.2 Tg sulphur.

I. A Regional Sulphur Budget for Northwest Europe

The problems and findings attached to estimating a budget for the atmosphere of a region are demonstrated by a calculation for Northwest Europe (Rodhe 1976).

The region studied is bounded by 65°N, 45°N, 10°W, and 250°E with an area of 4.62 million square kilometers. The following data have been used for years around 1973:

Non-pollution sulphur in precipitation, 0.2 mg per liter (Nordø 1976)
Sulphur deposition in precipitation from Sweden's Case Study (Bolin 1971)
Concentration of SO_2 sulphur in surface air, (LRTAP) data)
Deposition velocity of SO_2, 0.5 to 1 centimeter per second
Man-made sulphur emissions, 13 Tg per year

It is further assumed that the pollutant part of the air concentrations is the same as that of the rainwater sulphur.

The resulting balance is given in Table 2.

When comparing the net export from the region with the emission (about 30 percent), it must be remembered that there is some import into the region from the neighbouring areas, mainly from Eastern Europe, and that therefore the gross flux out of the region should be somewhat greater.

m. Sulphur: Trends and Implications

Global impact. It has been suggested that a general increase in sulphate particles might take place because of fossil fuel combustion and that these form a haze that might increase the albedo of the earth, thereby changing its radiation balance. On the other hand, in the data on sulphur/sodium ratios obtained from dated ice cores in Greenland (Koide and Goldberg 1971) there is no observational evidence of a change in this ratio paralleling the industrial development. There are few other reliable data on the subject.

Regional impacts. The major impact of fossil sulphur is on the regional scale. It is converted into sulphuric acid, which on deposition, dissolves equivalent amounts of any basic minerals present in the soils. The effect is then an increased rate of leaching from soils. When the soil cover is thin or consists of bogs, the deposited acid will accumulate in freshwater systems, lowering the pH to such an extent that a drastic change in biota takes place. This is at present the case in parts of Scandinavia and in some areas in North America. It should however, be pointed out that acid deposition on land is not due to fossil sulphur alone. Reduced sulphur coming from ocean areas will also be deposited on land as sulphuric acid and thus also contribute to the leaching of soils.

Man's addition of fossil sulphur has increased leaching of soils considerably in some humid regions. To what extent this leaching is decreasing the growth rate of coniferous forests is a subject under current discussion and so far there is no conclusive evidence. Because of the appreciable storage of nutrients in soils it may take a considerable time before the effects of leaching can be discovered. There is also the possibility that the acid deposition might affect nitrogen fixation by microorganisms in the soil thereby reducing soil productivity. Nitrification is inhibited by acidity, and this process is known to be sensitive to external changes. These are examples of a coupling between cycles of different elements. In contrast to the processes in humid regions, in arid areas sulphates are deposited in the process of soil salinization.

n. Further Research on Nitrogen, Phosphorus, and Sulphur Cycles

It is obvious that there are serious gaps in knowledge of the biogeochemical cycles of nitrogen, phosphorus, and sulphur. Inventories are needed, in particular for nitrogen, phosphorus, and sulphur in soils, since soils constitute a considerable storage. Such inventories will most likely reveal geographic patterns whose recognition will aid understanding of biogeochemical processes and their dependence on the physical and chemical environment (see Section C3 below). It is desirable to investigate the dynamics of major compartments, and especially the dynamics of soils in order to permit forecasts of effects of human activities. More should be known about the rapid turnover within each compartment and the transfer rates between compartments.

In the nitrogen and sulphur cycles, the atmosphere is a compartment for which knowledge is least complete. Phosphorus is a minor component of the atmosphere, but concentrations and origins of various phosphorus compounds are unknown. Patterns of deposition from the atmosphere are unknown over large areas. Extensive data collection on a routine basis will be required. Better techniques are needed for measuring air and precipitation concentrations of almost all compounds discussed in this section, particularly for measurement of background concentration values such as those found outside cities and industrial regions and in the free atmosphere.

More specific research prolems can be identified for each of the three elements.

Nitrogen. Although denitrification is an important process in the cycling of nitrogen, its rates in nature are poorly known. The influence of factors such as nitrate concentration, soil water content, and oxygen concentration on reaction rates and the N_2O/N_2 ratio of the gaseous end-product should be investigated in terrestrial and aquatic habitats. Geographical variations should be determined. It is important to verfify whether the soil can act as a sink for N_2O, and if so whether that leads to a further reduction to nitrogen gas or assimilation of nitrogen by the soil microorganisms. A possible tropospheric sink for N_2O should also be explored. Deepened knowledge of the atmospheric N_2O cycle would enhance the capacity to forecast future N_2O concentration levels as they may influence the ozone layer.

Little is known about the rates of biological nitrogen fixation in non-tropical waters. The possible environmental effects of increased biological nitrogen fixation should be examined. The possibility of genetic transfer of nitrogen fixing ability to presently non-fixing species and the resultant effect on the local and regional nitrogen cycles should be assessed. With a view to diminishing use of nitrogen fertilizers, several aspects of biological nitrogen fixation should be investigated in the hope of finding suitable species and efficient systems for use with present or new management techniques. Although the possible effect of heavy metals, pesticides, and other pollutants on nitrogen fixation has already been investigated in some detail, a complete overview on the effect on the nitrogen cycle is needed.

Methods should be sought to minimize any adverse effects, such as leaching of nitrate from soils, or decrease in biological nitrogen fixation, from management practices, including the use of nitrification inhibitors. This will become more important as the prices of nitrogen fertilizers increase.

Because nitrogen flows are variable on a regional scale, especially with regard to ammonium, local and regional nitrogen budgets of $NO_x(NO_3^-)$. and NH_3 (NH_3^+)

are needed to better elucidate man's impact. These would assist in evaluating the effect of changes in land use, including urbanization, on the nitrogen cycle.

To the degree that NOx is produced in gaseous form from soils as well as from combustion processes, it would be an important factor in accounting for the observed NOx concentrations in the atmosphere and should be investigated. Further measurements on background levels of NOx, and of NH_3, in the atmosphere are desirable.

Phosphorus. The concentrations of phosphorus and the origin of phosphorus compounds in the atmosphere are unknown and should be investigated. Understanding the formation of ocean sediments, and information about aeolian transport of phosphorus-laden dust from land to ocean would be valuable.

Much information is available concerning the use of fertilizers. However, to be able to minimize the use of phosphorus fertilizers, the efficiency of various forms should be evaluated.

Much of the phosphorus loading of waters affected by eutrophication originates from industrial and household consumption rather than from fertilizers. Means by which such uses of phosphorus could be reduced should be investigated. Studies on the use of phosphorus from sewage sludge should be continued. The effect of various forms of sewage treatment on the distribution of phosphorus, as well as nitrogen and sulphur, should be investigated.

Sulphur. In order to be able to estimate the total inventory and ground deposition of atmospheric sulphur, more detailed measurements are needed on the concentration of SO_2 and sulphate aerosols (particularly in surface air in remote areas over the continents), as well as in higher layers of the atmosphere (particularly in the 5 to 10 kilometer region) at a few different latitudes. Measurements of sulphate concentration in cloud droplets on a world scale and of wet deposition of sulphate in remote areas, are recommended, provided that the problem of contamination can be handled properly. In general, the basic chemistry of sulphur compounds in an atmospheric environment also needs to be understood better.

An important part of the sulphur cycle is the production of reduced, volatile sulphur compounds (hydrogen sulphide and dimethyl sulphides), but the amounts thus released from decomposing organic matter are not known. The most important areas for this production may be interidal flats. In situ measurements from such areas are urgently needed. Measurements are recommended for air and precipitation concentrations of the various sulphur compounds in coastal areas with tidal flats and at different distances from the coast, and where the anthropogenic contribution is either small or known.

Better data on sulphur in river runoff are needed, especially as sulphur is not included in the UNESCO inventory on world river discharges into the oceans.

It is possible that the present sulphur deposition from the atmosphere in industrial areas with intensive agriculture is sustaining the crop yields, and that a reduction in atmospheric sulphur fall-out would affect the production from some crop lands. This should be investigated by making local sulphur budgets. The possibility of foliar SO_2 absorption should be taken into account in this context.

The effect of acid precipitation on primary production should be assessed, both on a functional level and at the ecosystem level. The possibilities for drastic changes in, for example, leaf/needle pH and the resultant effect on photosynthesis and phyllosphere organisms deserve examination.

3. Carbon

A major global concern is the effect of human activities on the biogeochemical cycle of carbon. The release of carbon from fossil fuels and changes in the terrestrial carbon pool caused by agricultural and forestry practices are large enough to be significant in natural global processes. A schematic representation of the global carbon cycle is given in Figure 6. Ever since the Industrial Revolution there have been increasing anthropogenic CO_2 emissions to the atmosphere. These releases reached about 2,000 million tonnes per year in 1900 and about 18,000 million tonnes in 1974 (Keeling 1973, Rotty 1975) (Figure 7).

There are three principal forms of carbon in the atmosphere (carbon monoxide, carbon dioxide, and methane). During the decade 1959 to 1969 atmospheric carbon dioxide steadily increased by a total of 6.8 parts per million (ppm). With an assumed preindustrial concentration of 290 ppm, the increase is approximately 50 percent of the total estimated industrial release of carbon dioxide to the atmosphere (Bolin and Bischof 1970, Ekdahl and Keeling 1973, Woodwell and Pecan 1973, Bolin 1975b).

Methane in the atmosphere is of recent biological origin. It probably reacts with OH-radicals proceeding through a chain of reactions which includes carbon monoxide and ends with carbon dioxide. Therefore, a major portion of the carbon monoxide in the atmosphere would also be of recent biological origin.

Estimates of oceanic carbon pools vary by a factor of three for living matter and a factor of six for dead organic matter. Estimates for terrestrial carbon, particularly dead organic matter, are less certain. They range from 700 to 7,000 units. The terrestrial pool is of special interest because of the large immediate effects human activities can have on it (Hutchinson 1954, Reiners 1973, Whittaker and Likens 1973).

Estimates of exchanges between the various carbon pools in the global system, especially those related to biological processes, are uncertain. Exchanges within the ocean can be estimated using radiocarbon measurements. Estimates of the rate at which oceans can remove carbon released to the atmosphere by the burning of fossil fuels account for only about 50 percent of the amount released. This could mean that the carbon is being assimilated by the terrestrial pool, but it seems unlikely.

The movement of carbon within the oceans has a prominent role in determining the atmospheric concentration. An important part of the oceanic carbon cycle is the assimilation of carbon into living matter in the surface waters. This, in turn, is controlled by the amount of nutrients, such as phosphorus, available in those waters. Carbon and nutrients are typically depleted in surface waters and relatively abundant in deeper waters because they are incorporated in organic matter which, as waste material or dead organisms, sinks to the deep waters where it is released by

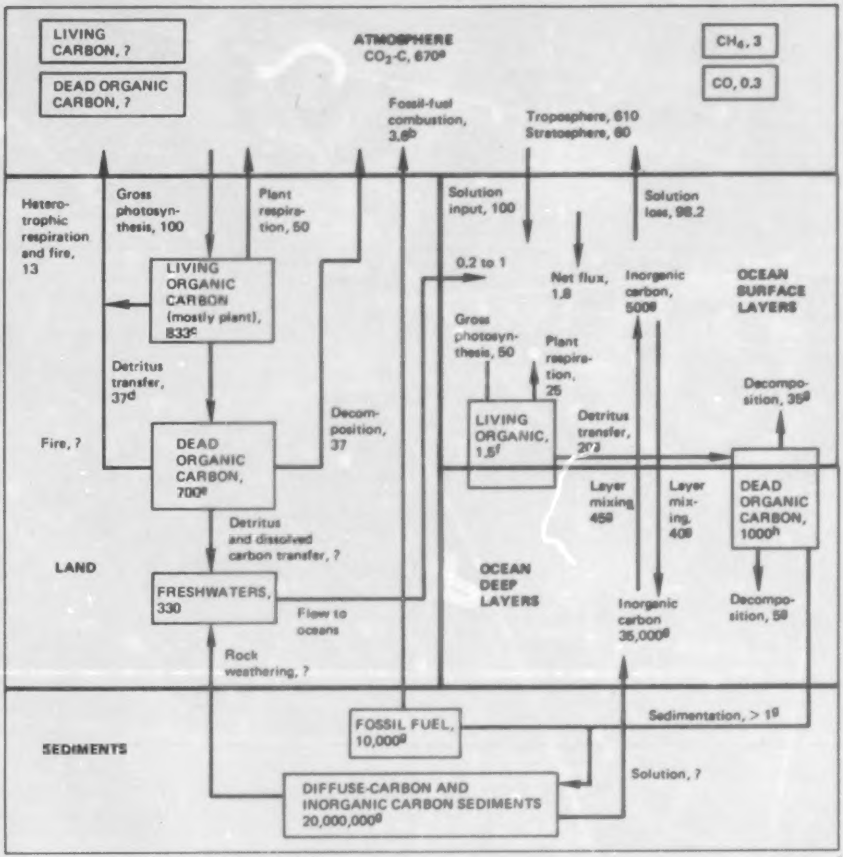

Figure 6 Diagrammatic model of the global carbon cycle. Estimates are given below. Question marks indicate that no estimates are available. Figures are all in billions of metric tons of carbon and are derived from estimates of Brookhaven Symposium participants unless otherwise noted. The following are alternative estimates; (a) Other estimates are 683 (SCEP, Ref. 1, page 161) and 700×10^9 tonnes (Bolin), (b) SCEP, Ref. 1, page 304, (c) Bolin estimates 450×10^9 tonnes, (d) Bolin estimates 25×10^9 tonnes, (e) Bolin, based on Delviche's nitrogen estimate and a carbon/nitrogen ratio of 12, an alternative estimate is $9{,}000 \times 10^9$ tonnes, (f) Bolin estimates 10×10^9 tonnes, (g) Bolin, (h) Bolin estimates $3{,}000 \times 10^9$ tonnes (modified from Remers 1973b)

decomposition. There is, therefore, a danger that interference with the biological processes in the surface waters of the oceans could have a profound effect on the atmospheric concentration of carbon dioxide.

In summary, the world biogeochemical carbon cycle is understood qualitatively, the various reservoirs and pathways being indicated in Figure 6. A number of

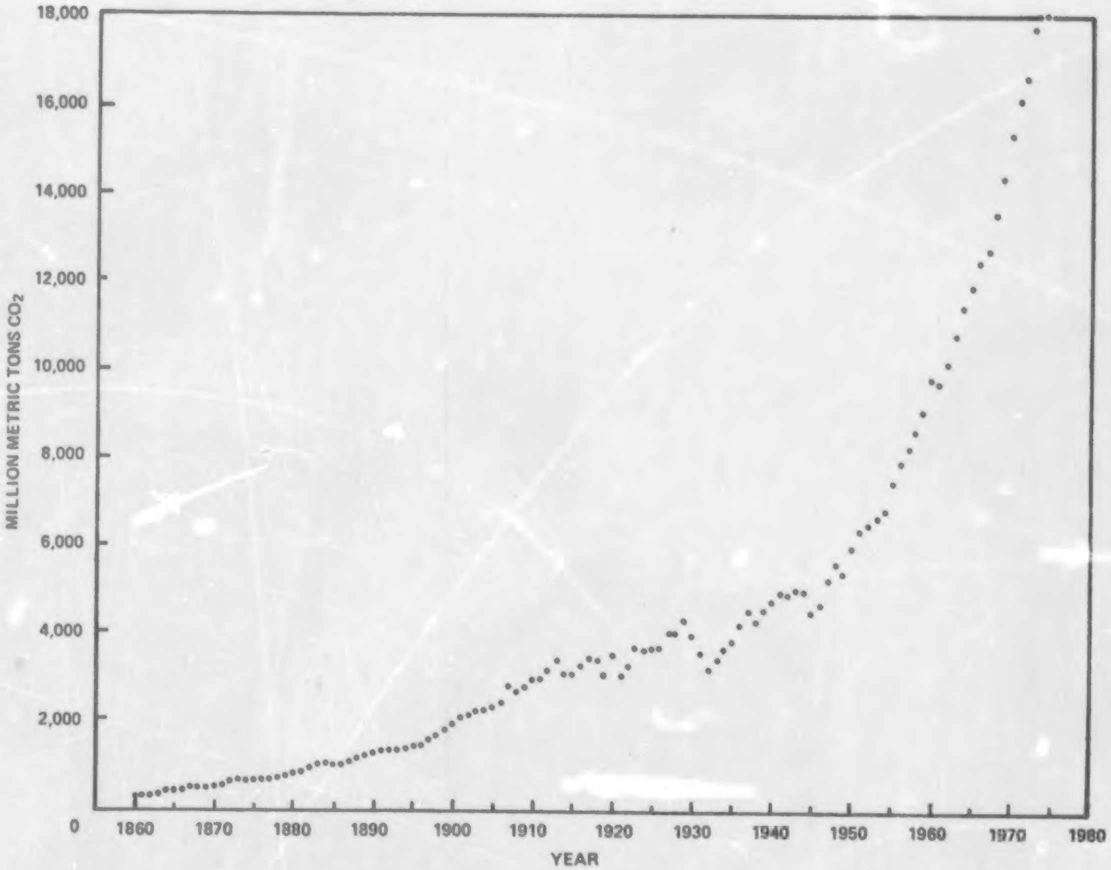

Figure 7 Annual production of CO_2 from fossil fuels and cement (Keeling 1860–1959, Rotty 1960–1974)

quantitative models have been proposed which, although still rather crude, indicate major increases in the atmospheric CO_2 concentrations during the next 200 years. In the model of Bacastow and Keeling (1973), for example, the world is divided into 6 boxes: the stratosphere, the troposphere, the ocean surface mixed layer, the deep ocean, and the continental biosphere (divided into long-lived and short-lived biota). Using present estimates of proven fossil fuel reserves, and assuming that the rate of increase of the consumption of fossil fuels will diminish, Bacastow and Keeling have computed the ultimate atmospheric CO_2 concentrations for several different assumptions concerning the uptake by the oceans. The results are rather alarming, indicating at least a fourfold and perhaps an eightfold increase in CO_2 concentrations during the next 200 years. Additional studies of the global carbon cycle should therefore be encouraged as a matter of urgency.

The highest priority should be given to research on the terrestrial biosphere including inventories and dynamics of living organic matter, inventories and dynamics of the dead organic matter pool, and the dynamics of photosynthetic processes. Perhaps ecosystem models could be of help, once properly developed, to express quantitatively the dynamics of the terrestrial biosphere.

Second in priority is the continuation of atmospheric monitoring of carbon dioxide. Although it is at present difficult to relate this information to the rest of the carbon system, a carefully documented history of atmospheric carbon dioxide will be most valuable when better knowledge of the terrestrial biosphere emerges. The WMO is playing a valuable role co-ordinating the global atmospheric monitoring efforts.

Additional research should be directed toward the equilibration of calcium carbonate in the oceans and deriving a history of atmospheric carbon by using the oceanic sedimentary record.

C. CLIMATE

1. Introduction

Man has always been profoundly influenced by climate. In early times, whole civilizations were sometimes destroyed by drought and famine while even in the present decade the Sahelian drought is evidence of the enormous repercussions of a succession of dry years.

In the first half of this century, there was considerable optimism that the impact of climatic anomalies could be almost completely eliminated through large engineering works and technology (irrigation, flood-control, plant breeding, fertilizers, and pesticides). Unfortunately, there are recent signs that the trend has been reversed. Land-use practices are designed today to optimize yields during normal environmental conditions, but sometimes at the expense of increased susceptibility to extremes.

There is another reason why climate has been a recent topic of discussion. The view has been expressed that man may be inadvertently changing the global climate in irreversible and possibly harmful ways. This line of reasoning is difficult to refute or to accept without a deeper understanding of the nature of climate. What are the causes of climate fluctuations? Are future climates predictable and, if so, in what sense?

It is for these reasons that the study of climate is a priority item over the next several decades.

2. World Climate: Past and Present

a. Types of Climatic Data

Climatic data are obtained from:

(i) Surface weather observing networks, first established in the middle of the nineteenth century, and upper-air networks which began in the 1930's and have recently been extended by satellite observations. The records of a few individual climatological stations date back to the late seventeenth century.

(ii) The written word preserved in diaries, legal and church documents, and so forth. Quite frequently, phenological events such as the blossoming of cherry trees and the breakup of ice on rivers have been recorded. Information of this type can be used to infer some features of the climate over the last 2,000 years or so.

(iii) Palaeoclimatological evidence, such as radiocarbon dating, tree-ring analysis, pollen studies in peat and lake sediments, glaciology, palaeopedology, palaeogeology, and studies of deep sea sediments. Palaeoclimatology provides a focal point for scientists from many different disciplines.

b. Some Properties of Climatic Data

The distribution of weather-observing stations is so uneven that there is difficulty in determining hemispheric or sometimes even regional climatic trends. This problem is heightened by the fact that during the last 50 years many stations were established at airports, where increasing urbanization has since taken place. Land-use changes often have a larger effect on local climate than does a global trend.

Meteorological observations, even at 'ideal' sites, contain three kinds of correlations (Figure 8).

(i) In the first place each observation has a 'memory' and its value is correlated with the previous value. In the case of temperature, for example, there are diurnal and annual cycles as well as long-term upward and downward oscillations in the mean values. An average obtained from a record of given length rarely converges to a 'true' mean as the sampling interval is lengthened. Nevertheless, an average value over a specific 30-year period (e.g., 1941–1970) is often computed by National Meteorological Services in order that spatial comparisons can be made.

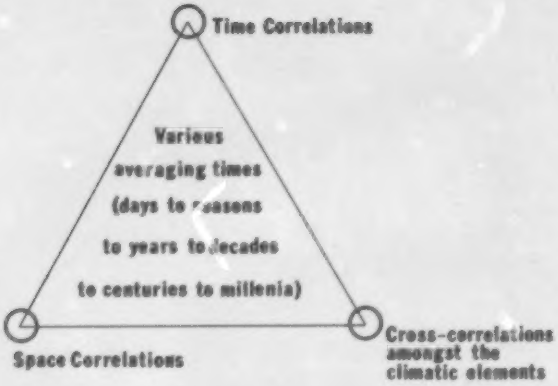

Figure 8 Correlation of meteorological observations

(ii) Meteorological observations contain not only correlations in time but also in space. The weather at a point is similar, to a certain extent, to that in the surrounding region, on time scales of hours, years, and centuries. This coherency is demonstrated by the existence of the Northeast Trades, the Westerlies, and by the global organization of climatic anomalies. For example, a drought in North America often occurs in conjunction with other anomalies around the world. Determination of the extent of these connections is an active area of research (Bjerknes 1962, Namias 1957a, 1957b). There exists the possibility that some of the spatial correlations may be time lagged, permitting predictions of at least some features of the climate from a knowledge of anomalies during the previous season a thousand kilometers or more away.

(iii) The third dimension of the climate matrix indicates the existence of many cross-correlations among the climatic elements. There are correlations between temperature and sunshine, humidity and precipitation, and so forth.

c. *The Natural Variability of Climate*

For the past 8,000 to 10,000 years, the earth has had a relatively warm interglacial climate. There have been other periods in the last 2 million years, none of which apparently lasted more than 10 to 20 thousand years.

World climate has also fluctuated significantly on a time scale of centuries. There was a warm spell in Northern Europe from about 1000 to 1300 AD followed by a cold period between 1550 and 1700 AD.

In the present century, the temperate and arctic zones of the Northern

Hemisphere were exceptionally warm until about 1940 when cooling began. The spatial organization of the cooling was remarkable, being concentrated in the Spitzbergen/Franz-Joseph Island region (a drop of nearly 6°C in winter temperatures at Franz-Joseph). Meanwhile in New Zealand, the reverse trends were experienced (Salinger and Gunn 1975); the period 1900 to 1935 was the coldest in recorded history while the climate has since become warmer. That this is not an isolated result is indicated by a recent study of Australian climate (Tucker 1975). Although the data base in the Southern Hemisphere was admittedly incomplete, the associated world pressure anomalies were consistent, revealing that (Salinger and Gunn 1975):

(i) when the subtropical anticyclones were farther north than usual, as in the period 1900 to 1935, the weather was warm in the Northern Hemisphere and cool in the Southern;

(ii) when the subtropical anticyclones were farther south than usual, as in the period 1950 to 1970, the reverse temperature regimes prevailed.

This is a good example of spatial coherence on a time scale of decades. Scientists in many disciplines have contributed data on past climates. The task of synthesizing these data is associated especially with the names of Lamb in the UK, Flohn in FRG, and Kutzbach and Mitchell in the USA.

d. Man's Impact on Climate

Man changes local climate in many ways. The surface heat balance is substantially modified whenever a forest is cut, a field is ploughed, snow is removed, or a parking lot is paved. The expression 'urban heat island' is widely used to indicate that temperatures in built-up areas are higher than in the surrounding countryside, but the other climatological elements are also affected. With the growth of the megalopolis, these local anomalies are becoming regional.

Other possible reasons for local climate modification can be cited:

(i) river diversions or control, creating new lakes or changing the salinity and ice-cover of coastal zones;

(ii) the destruction of tropical forests, changing the surface heat balance and roughness, and reducing evaporation (Potter et al. 1975);

(iii) changes in agricultural and forestry practices, such as slash burning, and irrigation affecting the surface heat balance;

(iv) changes in the numbers and/or sizes of condensation nuclei emitted to the atmosphere, affecting cloud formation and dissipation; and

(v) releases of krypton-85, changing the electrical properties of the atmosphere. This 'problem of the future' could affect thunderstorm activity and associated precipitation patterns (Boeck et al. 1975).

There is no evidence to suggest that any of these mechanisms influences the synoptic-scale weather patterns crossing overhead, although the micro- and even the meso-climate may be considerably affected. In contrast, it has been known for 25 years that the Great Lakes (a large heat source in autumn and winter; a small heat sink in spring and summer) influence the movement and development of weather systems in Eastern North America (Danard and McMillan 1974). Thus the possibility exists that some of the factors listed above could ultimately affect the general circulation especially if human population expansion is accompanied by increased urbanization and energy generation. According to Sawyer (1974), an increase of about 50-fold in European or North American heat releases could 'produce a climatic change comparable with the year to year variation which we experience naturally'.

Another possible way of affecting climate is by modifying the atmospheric radiation balance, which might lead to changes in the general circulation. Particulate matter and a few gases, especially CO_2, which absorb and re-emit terrestrial radiation in selected wave-bands are candidate substances. There is also some concern about gases such as chlorofluorocarbons that not only could affect the radiative balance of the atmosphere but also could react chemically in the stratosphere, disturbing the ozone layer (see Section 4(c) below).

Bryson (1974) captured public attention with his hypothesis that the atmospheric cooling in high latitudes of the Northern Hemisphere since 1940 had been caused in part by an increase in particulate matter released by man. Bryson also reasoned that because the temperature difference between the equator and the North Pole had increased, the zonal wind fields had strengthened, shifting the subtropical anticyclones towards the equator, and contributing to the Sahelian drought. Bryson's hypothesis is now disputed; cooling in northern latitudes is perhaps an effect rather than a cause of changes in the pressure patterns (Schneider and Mass 1975). Nevertheless, Bryson has had a beneficial effect in stimulating research into the complex problems of world climate.

3. The Prediction of Climate

a. Statistical Correlations

A global observing programme of WMO called the World Weather Watch (WWW) provides the data required to determine the state of the atmosphere at any given time, and to make predictions for the next 1 to 2 days, with broad outlooks for an additional 3 to 5 days. As the time span increases, the forecaster's skill diminishes until his predictions are no longer better than those based purely on persistence of existing conditions or on climatological average values.

To predict weather and climate over time periods of more than a few days, the statistical approach has often been used, extending the time and space correlations that are known to exist amongst meteorological series. One variant of this approach is based on the premise that a monthly/seasonal climate anomaly should have at least some slight effect on the climate of the next month/season at the same location, due to the time lag of the underlying surface in its response to the atmospheric anomaly. However, studies of this type have met with little success at least for seasonal forecasting (Kanestrøm 1975).

As a second variant, investigators may seek to correlate an anomaly in the condition of the underlying surface with:

(i) a climatic anomaly at the same location; or

(ii) a climatic anomaly in some other region, perhaps many kilometers away, and at some later time.

Case (i) is of trivial interest because the relation is so direct: if snow falls on a grass surface, for example, the heat budget is drastically modified. Case (ii), on the other hand, implies that there has been a change in the world pressure patterns, and is therefore of considerable importance particularly if such correlations could be used to predict climatic anomalies a few months ahead. In this connection, special attention has been given to the climatic effects of large-scale sea surface temperature anomalies. As an example, Namias (1970) has found that the relatively cool decade of the 1960's in the Eastern United States was associated with a relatively warm anomaly in sea surface temperatures in the North Pacific. However, one of the questions that needs to be answered is the extent to which the ocean is master or the extent to which it is slave to the atmosphere. This field of research is promising and should be encouraged, one of the practical applications being the development of hemispheric and world scenarios for food production.

As a third variant (Lamb 1965), systems have been devised for classifying daily air-mass types or daily weather patterns over a region. The annual frequencies of each type are then correlated with values of the climatic elements or anomalies.

Finally, there are methodologies which cannot readily be classified. In many such cases, the regression equations show statistical significance but they fare badly when applied to independent data. This is because: (a) there is difficulty in obtaining a random meteorological sample, one of the prerequisites for employing classical statistical theory; and/or (b) the regression equations are not based on physically plausible hypotheses.

The possibility of using statistical techniques to predict large-scale climate anomalies several months in advance is an attractive but still elusive goal. At a recent symposium, the participants agreed that there were too few scientists actively working in this field, and that there was need to develop several additional specialized research institutes around the world. The symposium was held in connection with the 16th General Assembly of the International Union of Geodesy and Geophysics (IUGG), at Grenoble, France in 1975.

b. Numerical Models

The numerical models used operationally to make short-range weather forecasts require data on the current state of the atmosphere. This information is obtained routinely from the WWW which includes more than 7,500 surface stations, 600 upper-air stations, and satellite observations. These data are used to construct the current three-dimensional fields (at 5 to 10 heights) of temperature, pressure, water vapour, wind direction, and wind speed. The governing equations are then solved for a series of discrete time steps (usually about 10 minutes in real time for each step), using finite differencing (grid squares of 381 × 381 km^2). Often included are the equations of motion, of thermodynamics and of water vapour, and the balance equations of heat and water at the surface of the earth.

When these models are started up from a very simple initial condition such as an isothermal atmosphere, and with idealized topography, they produce patterns that look like those observed on real weather maps, and the resulting climatological statistics also resemble real data. Some of the models which incorporate hydrologic processes can actually recreate the major rivers of the world. This leads to the speculation that the atmospheric effects of man-made changes (such as an increase in CO_2 concentrations, tropical deforestation, or introduction of a forest cover over a desert) can perhaps be simulated correctly, and a number of such simulations have been reported (Manabe 1975, Potter et al. 1975). The results have been exciting, but a number of technical questions must be resolved, including the following:

(i) How are the simulations to be verified?

(ii) How much scale resolution is needed?

(iii) How are radiative effects of clouds to be characterized?

(iv) How are the land surfaces (such as orography plus a patchwork of towns, farms, woodlots) of the world to be modelled as sources and sinks of heat and water?

A drawback with these simulations is their cost. Because the computer running time is only about 10 to 100 times faster than nature itself, the cost is so great that the number of climate simulations performed so far does not exceed 50. Consequently, many simplifications have been introduced, two well-known examples of simplified models being those of Budyko (1969) and Sellers (1973). In general, the problem is to couple the atmospheric general circulation to oceanic, sheet ice and land biosphere models in a realistic way but without excessive computer costs. The various interacting submodels are illustrated schematically in Figure 9 (Bolin 1975a). There are many couplings and feedback mechanisms, some of which have time lags of decades or even centuries. The processes are, in general, non-linear. A comprehensive review of the physical basis for climate and climate modelling, with special emphasis on the interactions between atmosphere, oceans, ice, soil, and vegetation, has been given in a recent report of the Global Atmospheric Research Programme (GARP) (Bolin 1975[illegible]).

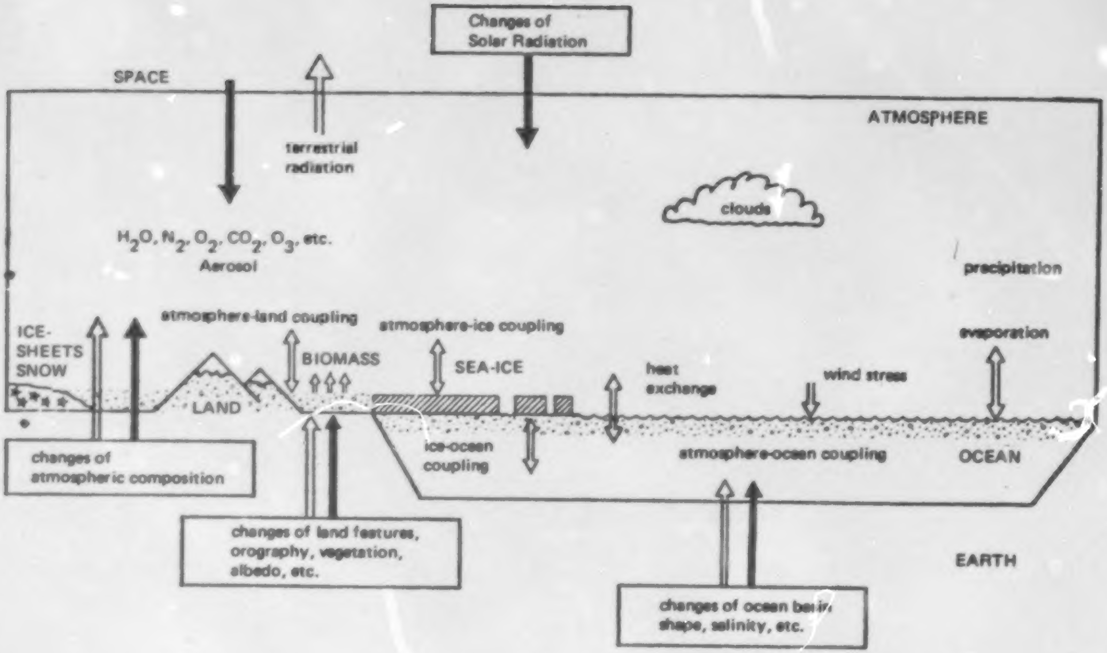
Changes of Solar Radiation
SPACE
terrestrial radiation
ATMOSPHERE
clouds
H_2O, N_2, O_2, CO_2, O_3, etc.
Aerosol
precipitation
atmosphere-land coupling
atmosphere-ice coupling
evaporation
ICE-SHEETS SNOW
BIOMASS
SEA-ICE
heat exchange
wind stress
LAND
ice-ocean coupling
atmosphere-ocean coupling
OCEAN
changes of atmospheric composition
changes of land features, orography, vegetation, albedo, etc.
EARTH
changes of ocean basin shape, salinity, etc.

Figure 9 Schematic illustration of the components of the coupled atmosphere – ocean – ice – land surface-biomass climatic system. The full arrows are examples of external processes, and the open arrows are examples of internal processes; biomass is represented by stippling (Bolin 1975a)

Some of the factors that may affect climate are external (astronomical geometric factors, changes in solar radiation, volcanic eruptions) and the behaviour of these factors is not affected by the state of the atmosphere. Other factors are internal (extent of sea ice, glaciers). Schneider and Mass (1975) have stated that 'perhaps the chief open question in climate theory' is the extent to which 'the statistics of the actual climatic system can be attributed to internal or external causes'.

Some of the astronomical factors (periodicities in orbital characteristics such as precession, eccentricity, and obliquity) operate on such long time scales (from 10^4 to 10^5 years) (Berger1975) that they are of no immediate concern. In a similar class are geophysical processes such as mountain-building and continental drift. Nevertheless, the study of such factors is of considerable practical importance. It would indeed be valuable if it could be established that ice ages were associated with particular astronomical and/or geophysical events (Weertman 1976).

On a time scale of years to centuries, the external factors that might influence climate include volcanic dust and sunspots. Schneider and Mass (1975) have created an 'index' reflecting the combined behaviour of these two factors, and have derived annual values of the index dating back to 1600 AD. This series has been introduced into a climate model to predict year-to-year variation in 'planetary radiative equilibrium temperature'. Although this temperature need not be the same as, nor even correlated with, the surface temperature in any given region, the similarity of Schneider and Mass' predicted values with temperatures inferred from ice cores, trees rings, and European temperature records is rather remarkable. Schneider and Mass emphasize the need for:

(i) better measurements of solar variability;

(ii) deeper understanding of the effects of volcanic dust on radiative heating rates in the atmosphere;

(iii) an improved reconstruction of the global surface temperature history;

(iv) improved parameterizations of atmospheric processes; and

(v) increased support for studies of the predictability of volcanic and solar activity.

In addition to the external forcing mentioned above, there are internal processes (see Figure 9) influencing climate. Paramount among these are those occurring in the world oceans. These vast bodies of water are part of the climate system that display considerable thermal and mechanical inertia. Numerical modelling of the oceans has only just begun, and there is still a lack of suitable data for model verification. Here it should be pointed out that the oceanic equivalent of the atmospheric cyclonic scale is only about 100 km (as compared with 1,000 km in the atmosphere), so that the observational requirements are severe. (A list of theoretical and experimental studies that need to be undertaken has been given in Bolin 1975a.)

An important question being raised is the degree of self-regulation (homeostasis) in the atmosphere. Could an ice age occur in the absence of a change in externalities? Is there a possibility of runaway processes or of large overshoots? It is a surprising fact that the earth's climate has changed so little over decades and even centuries, even though there is sometimes a great year-to-year variability. In this connection, the historical evidence on the length of time required to enter an ice age is confusing (tens of years or thousands of years?).

Research into these topics has centred around the concept of an 'almost-intransitive' system, a phrase introduced by Lorenz (1968). If all initial states of a system lead to the same set of statistical properties, the system is said to be transitive. If initial states lead to more than one set of statistical properties, the system is said to be intransitive. The third possibility is an almost-intransitive system, which occurs 'if there are different sets of statistical properties which a transitive system may assume in evolving from different initial states through a long but finite time span' (Bolin 1975a, Lorenz 1975). This last possibility, which could lead to cases of mistaken identity, has led to a rather broad discussion on the predictability of atmospheric processes. The word 'predictability' has been used in several ways and needs to be defined rather carefully. At least two sorts of predictions can be distinguished (Lorenz 1975):

(i) predictions of climatic sequences; and

(ii) predictions of the long-term statistics that might ensue if the boundary conditions were changed, for example, if there were a major increase in atmospheric CO_2 concentrations.

The extent to which climate is predictable in either of these senses is unknown. The consensus of a recent workshop (Bolin 1975a) was that: 'the fact that one can construct a climate model that embodies the totality of physical processes in a realistic way does not ensure that it can necessarily predict a unique sequence of climatic events – even in some statistical sense. The extent to which this kind of predictability is possible is yet to be established'.

4. Some Current Research Activities

a. Introduction

Information on climate, climate change, and climate modelling can be found in many publications (SMIC 1971, Stewart 1973, Bolin 1975a, 1975b, CIAP 1975a). A new journal, *Climatic Change*, edited by Schneider and published by Reidel Pub. Co., has just appeared, while two major workshops have been held in recent years (SMIC 1971, Bolin 1975a), as well as a number of symposia (WMO 1975a). The following sub-sections will therefore be restricted to a discussion of only three selected topics of current interest: the Sahelian drought, stratospheric ozone, and the CO_2 problem.

b. The Sahelian Drought

The Sahelian drought became perceptible in West Africa in 1965, reaching its peak in 1972 when rainfall was close to the hundred-year minimum in many parts of the Sahel. Although rainfall returned to normal in 1974, the effects of the drought have not yet disappeared.

The 'latest' drought always seems to be the worst, and in terms of its socio-economic impact, the Sahelian drought may indeed have been the worst in recent experience. However, hydrological data from the Senegal and Niger rivers reveal episodes of similar severity, one in 1910 to 1914 and another in 1940 to 1944 (Roche et al. 1975).

The human suffering in the Sahel has drawn public attention to the problems of arid and semi-arid regions; in fact, there will be a United Nations Conference on Desertification (General Assembly Resolution 3337 (XXIX)) in 1977. The scientific community has also been studying the problems of droughts and deserts, and there have been many recent publications (WMO 1975b). One of the most important meteorological investigations is that of Charney (1975).

The North African desert is a meteorological contradiction in the following sense. Although the surface temperature in summer is high, the region (the Sahara and Arabian deserts) is a radiative sink in summer (confirmed by satellite pictures). To maintain equilibrium, the air subsides and compresses, decreasing the relative humidity and cloudiness. Consequently, once a desert condition has been established, there is a positive feedback to maintain it. This much of the story is well known. However, Charney believes that there is a second mechanism of equal importance. As aridity increases, vegetation decreases, which causes an increase in the surface albedo, the ratio of the reflected and scattered solar radiation to the total incoming radiation. This increases the strength of the radiative sink at the top of the atmosphere and further feeds the process.

Charney has used a numerical model of the atmosphere to substantiate this hypothesis. When the albedo over North Africa was increased in the model from 14 to 35 percent, the inter-tropical convergence zone was shifted south several degrees of latitude and the rainfall in the Sahel was decreased about 40 percent during the rainy season.

Once this process has begun, other physical factors contribute to drought and desertification:

(i) wind erosion, caused by a reduction in vegetative cover, results in a decrease in germination of seedlings and an increase in desiccation of roots;

(ii) increased atmospheric subsidence, caused by the increased atmospheric dust load (see Bryson and Baerreis 1967), results in a decrease in cloudiness and precipitation; and

(iii) increased diurnal range of surface temperature and humidity, caused by a reduction in vegetative cover, results in a harsher microclimate for seedlings.

An important question remains to be answered. What causes a drought to end? In some cases, desertification may be almost irreversible. The Rajasthan desert in Northwestern India and Southeastern West Pakistan may have been formed in this way (Bryson and Baerreis 1967). But in other cases, the dry spells come to an end 'naturally'. Why?

In conclusion, it should be added that the Sahelian drought was not purely a meteorological phenomenon. A number of socio-economic factors can also be cited (UNESCO 1975):

(i) a reduction in animal diseases in recent decades due to advances in veterinary science, resulting in an increase in livestock populations thus placing considerable pressure on grazing lands;

(ii) an increase in the number of watering places in recent decades through various engineering works; this has had the unwanted side-effect of large-scale degradation of adjacent pastures;

(iii) a lack of understanding by governments of the traditional ways in which the pastoral nomads were in equilibrium with their environment;

(iv) a lack of perception of the environmental risks to which the populations were subjected.

c. *Stratospheric Ozone*

The stratosphere contains small amounts of ozone, a gas that has a major effect on radiative transfer and thus on the general circulation, including large-scale vertical motions. Ozone also shields the surface of the earth from receiving a part of the incoming ultraviolet light. The possibility of a disruption of the stratospheric ozone balance is therefore an important question.

Ozone is created by the action of solar ultraviolet radiation (200 to 250 nm) on oxygen, the main region of production being in the layer from 30 to 50 kilometers. Although produced at these altitudes and primarily in the equatorial region, the ozone layer usually has its maximum values in polar regions and at lower altitudes – the results of equator-to-pole transport processes. Destruction of ozone was at one time considered to take place simply through recombination with atomic oxygen. However, this process is relatively slow and calculations using it as a primary destruction mechanism tend to overpredict the amount of ozone. Other chemical reactions have therefore been proposed, including those involving hydrogen compounds (OH, HO_2), nitrogen oxides and, more recently, oxides of chlorine and bromine.

Comprehensive models describing the stratosphere must account for major singularities, referred to as 'stratospheric warmings'. These mid-winter explosive events are grossly at variance with climatological rates of heating and cooling. They are primarily polar phenomena. Large temperature increases (40 to 80°C) within a few days time are associated with a reversal of the basic circulation in the stratospheric polar night vortex from westerly to easterly flow. The sudden change in stratospheric temperature and circulation must have an important effect on the distribution of atmospheric constituents as well as on their chemical reaction rates.

Extensive reviews of the photochemistry of the stratosphere have been given (CIAP 1975b). The growing list of candidate threats to the ozone layer includes the following:

(i) high-flying aircraft (e.g., supersonic civil and military aircraft);

(ii) nuclear bombs;

(iii) halocarbons, such as 'Freon' (from aerosol sprays and refrigerants) and carbon tetrachloride;

(iv) nitrous oxides from fertilizers (McElroy 1975); and

(v) volcanic eruptions.

The effects of one or more of these are difficult to predict, partly because the stratosphere behaves dynamically; if ozone were destroyed at a particular latitude, the general circulation might adjust to such an extent that the global ozone distributions could not be predicted.

The special concern relating to (iii) and (iv) above arises from the fact that the time lag between ground-level release of a substance and its maximum effect in the stratosphere seems to be of the order of a decade. This long time lag, together with the fact that there is appreciable natural variability in the strength of the ozone layer (which makes it difficult to detect man-made changes) means that if no action were taken until a measurable impact on the ozone layer had been demonstrated, it would then be too late to avoid further effects.

The following programme (WMO 1976) should therefore be given high priority:

(i) additional monitoring of trace gases in the stratosphere (not only ozone but also N_2O, NO, NO_2, and chlorofluoromethanes);

(ii) establishment of monitoring networks for ultraviolet radiation; and

(iii) increased interdisciplinary research on the following topics:

  (a) the coupling between stratospheric chemical composition, heating rates and circulation, taking account of tropospheric-stratospheric exchange processes;

  (b) the influence on climate of changes in stratospheric ozone, involving quantitative treatment of the associated feedbacks using three-dimensional photochemical models;

(c) the biogeochemical nitrogen cycle, its possible modification due to man's activities and the implication for atmospheric chemistry.

(d) biological consequences of spectrum changes in solar ultraviolet radiation.

d. The Carbon Dioxide Problem

Since the beginning of the Industrial Revolution fossil fuels have been burned in increasing quantities. This has caused an increase in the concentration of carbon dioxide in the atmosphere. Various models and assumptions about fossil fuel reserves and consumption rates have been used in attempts to predict how far this trend will continue, and with what effect: some models suggest that atmospheric CO_2 concentrations could increase fourfold or even eightfold in the next 200 years.

The precise effects of such a massive increase are difficult to predict but they are likely to be of two main types.

(i) Climatic changes. The radiative budget of the atmosphere would be changed, causing changes in cloudiness, precipitation, and temperature. The numerical model of Manabe and Wetherald (1975) predicts that a doubling of CO_2 concentration would cause an average surface temperature rise of 2 to 3°C. However, the increase would not be distributed uniformly around the globe. Budyko and Vinnikor (1976) have suggested that global warming would reduce the pole-to-equator temperature differences, so diminishing the strength of the meridianal winds, reducing the transfer of water vapour from oceans to continents, and thus decreasing the rainfall averaged over all land areas.

No simulations of the effects of four- to eightfold increase in CO_2 have been undertaken, but it would be unwise to dismiss this possibility without exploration, particularly since the increasing burden of chlorofluorocarbons also affects the atmospheric radiation budget (Ramanthan 1975).

(ii) Increase in acidity of the oceans. A considerable part of the CO_2 added to the atmosphere finds its way into the oceans, and as more and more is absorbed the acidity of the sea is likely to increase gradually. The biological implications of this have not yet been examined.

Hafele and Sassin (1975) have suggested that the time required for a new energy production system to gain 50 percent of the United States market, starting from the 1 percent level, is about 60 years and in other parts of the world the time is likely to be even longer. This lends urgency to an assessment of the possible environmental effects of present day energy generation systems.

5. The Impact of Climate on Man

Living organisms have limits beyond which they cannot tolerate extremes of temperature, wind, and radiation. As the word acclimatization implies, however, most organisms are capable of some adaptation, a process which may involve

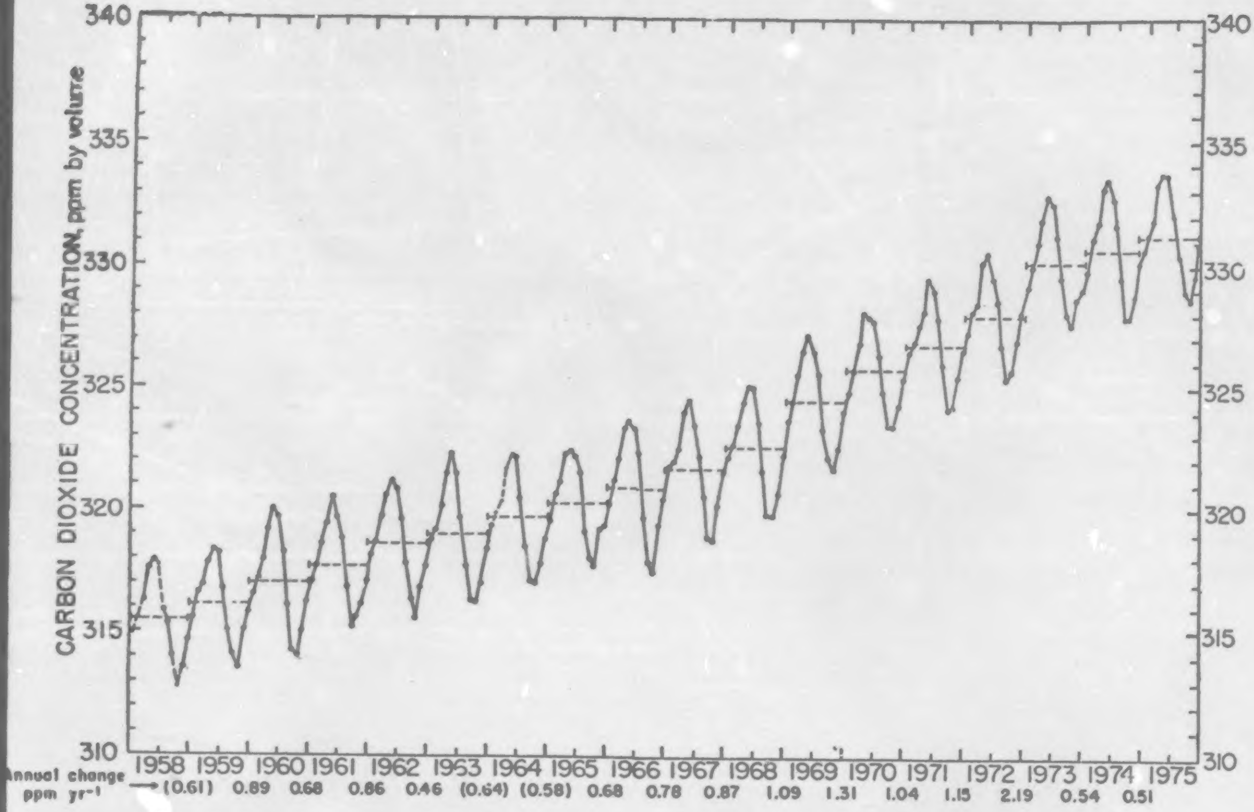

Figure 10 Changes in atmospheric CO_2 concentrations (based on Scripps 1974 manometric calibration)

physiological adjustments of the individual, or evolution of new ecotypes. The process may take place over times ranging from seconds to centuries, and there is quite often a lag between stress and response.

Ecosystems also respond to climatic change, both by adaptation of component organisms and by immigration of adapted species. Because of time lags, ecosystems may reflect past rather than present climatic conditions. Vegetation exhibits a degree of inertia dependent on: (a) its structure; (b) the extent to which it creates its own protective microclimate; and (c) the longevity and reproductive performance of its members. Ecosystems that developed during earlier and more favourable climatic conditions are sometimes fragile in the sense that fires, over-grazing, and forest cutting are likely to produce irreversible effects.

Climate seems to have its greatest impact on agriculture. The remainder of this section will therefore deal with that topic, although the fact should not be overlooked that nearly all of man's activities (agriculture, forestry, construction, transportation, and energy production) are climate-sensitive. For example, although the major decline in the anchovy harvest off the coast of Peru in 1972 was caused in part by over-fishing, there was also an oceanographic meteorological connection. The occurrence of the El Niño off the coast of Peru and a reduction in upwelling controls plankton production upon which the anchoveto feed (Wytki et al. 1976). These events were caused by climate anomalies and were associated with anomalies elsewhere around the globe (Flohn 1973, Flohn and Fleer 1975).

Climate and agricultural yields have fluctuated in the past and will continue to do so in the future, and climatic variability must also be taken into account when planning economic and social development. Other factors have an important impact on agriculture, such as the desire to optimize profits rather than yields. Although climate is not the only factor affecting yield, particular concerns for environmental managers are: (a) that year-to-year climatic fluctuations might become bigger than they have been in the last several decades; or (b) that the running-mean climatological values of temperature and other elements might change significantly; and (c) that these changes might occur too rapidly for man to adjust without major disruption.

Several international workshops on the subject of climate and food have been held recently: The Sterling Forest Workshop, at the Sterling Forest Conference Center in New York, in December 1974; The International Federation of Institutes for Advanced Study (IFIAS) Workshop in February 1975; and The Bellagio Conference sponsored by the Rockefeller Foundation in June 1975. Some common threads have emerged which can be woven together to yield the following recommendations:

(1) There is need for better understanding of the global organization of climatic anomalies, particularly those of vital importance to world agriculture.

(2) There is need for an improved world network for monitoring crop growth and yields. In some semi-arid regions, there is also a requirement for more climate stations.

(3) There is need to determine the carrying capacity of the world for various climatic scenarios. How much arable land exists? How could its use be optimized?

(4) There is need to develop contingency plans for unfavourable climatic episodes such as the 1933–1936 drought in the North American Midwest.

(5) There is need to accelerate research, building on IBP studies of novel food sources, into the development of new strains of crops with one or more of the following properties:

  (a) more tolerance to drought;

  (b) more tolerance to saline soils;

  (c) increasingly efficient use of water, the supply of which will diminish in some regions regardless of climate trends;

  (d) increasingly efficient use of solar energy; and

  (e) adaptability to a shortened growing season.

(6) There is need to accelerate research on strategies to improve the collection and storage of precipitation in soils, and the prevention of evaporation from soils: such conservation techniques are especially needed in dry-land (nonirrigated) farming and grazing.

(7) There is need to consolidate current knowledge and to encourage further research on microclimatological techniques for ameliorating unfavourable macroclimatological conditions, through aircraft dusting of snow surfaces with soot to accelerate melting, and through the construction of shelter belts to decrease wind speeds and air drainage corridors to reduce frost frequencies. The potential impact of some techniques of weather modification is such that thorough theoretical research should always precede operational testing.

(8) There is need to undertake, and disseminate widely, analyses of food-climate policy alternatives at the national, regional, and global levels, so that a public debate on these crucial issues can be started. In this connection, special efforts should be made to publicize the view that the climate fluctuates, so that average values for the last 30 years are not necessarily good predictors for the next 30 years. As mentioned by Winstanley (1973), it is probably no accident that much of the economic development and population expansion in French West Africa took place during a period of abnormally good rainfall: in 27 of the 39 years from 1920 to 1958, rainfall was above the long-term average.

Finally, mention should be made of some recent recommendations for climate research (WMO 1975c), in which it is urged that high priority be given to the following data synthesis and observational tasks:

(1) the synthesis of synoptic data (since about 1950) into hemispheric and global sets that would be readily accessible;

(2) the synthesis of data on past climate, with emphasis on the need for international co-operation in the retrieval of data from indirect and 'proxy' sources;

(3) the establishment of long-term monitoring programmes for climate parameters such as the extent of sea-ice and snow cover, anthropogenic heat releases, biomass of trees, and solar radiation at the top of the atmosphere; and

(4) specific observational studies for the development of parameterization techniques in numerical simulations.

Remote sensing is already important and will play an even greater role in years to come (Kunkel et al. 1975). Since 1968, information on snow and ice cover and on sea surface temperatures has been collected from satellites, although there is as yet no central intergovernmental repository for synthesized data. By the mid-1980's, vertically-integrated estimates of the atmospheric burdens of a number of trace substances should be possible. Another application of remote sensing is in the determination of crop acreages and crop yields. Because existing information is inadequate in many cases, the regression equations between yields and various climatic factors need to be improved, not only for predictions of current harvests but also for use in climatic scenarios. To close this gap, a research programme called LACIE (Large Area Crop Inventory Experiment) has been started (Hammond 1975). The objective is to use satellites to estimate the acreages of selected crops, and to develop better regression equations relating yield to current climatological data.

D. POLLUTANTS IN THE ENVIRONMENT

1. Background

Man has been polluting his environment since he began to live in large settlements, to burn fossil fuels, and to apply technology to the needs of city dwellers. The process accelerated during the Industrial Revolution with the introduction of steam power for factories and with greater concentrations of populations in manufacturing centres. The number and variety of pollutants increased markedly with the development of modern chemical technology in the last century.

Until quite recently these undesirable results of man's activities were accepted by most observers as the inevitable concomitant of technological advance. The arousal of a public conscience in these matters is of quite recent origin. It was sparked by unfortunate episodes where appreciable numbers of persons became ill or died from the effects of pollutants. It was also stimulated by articulate prophecies of impending disasters such as that of Rachel Carson in 'Silent Spring' published in 1962.

Public interest in these problems was focused by the United Nations Conference on the Human Environment held at Stockholm in 1972. Two of the recommendations of that conference were:

> *Recommendation 73* – 'It is recommended that Governments actively support, and contribute to, international programmes to acquire knowledge for the assessment of pollutant sources, pathways, exposures and risks and that those Governments in a position to do so provide educational, technical and other forms of assistance to facilitate broad participation by countries regardless of their economic or technical advancement.'

> *Recommendation 80* – 'It is recommended that the Secretary General ensure:
> (a) That research activities in terrestrial ecology be encouraged, supported and coordinated through the appropriate agencies, so as to provide adequate knowledge of the inputs, movements, residence times and ecological effects of pollutants identified as critical.'

These recommendations describe activities to be undertaken by the United Nations Environment Programme in that part of the action plan called 'Earthwatch'.

Pressure to undertake research and assessments of the effects on the environment and its inhabitants resulting from the release of pollutants has understandably increased. Considering the number of actual and potential pollutants, receptors, and environments, the requirements for investigation are enormous. Guidance is needed on which problems are the more urgent and on how to conduct research most economically to yield the most relevant results.

Perceiving this need, SCOPE began in 1971 to consider a project on Ecotoxicology to be conducted by a Preparatory Committee. The membership and activities of that Preparatory Committee are reported in Appendix C and Chapter 5.

Many other aspects of the possible effects of chemical substances released into the environment rightly attract international concern. The after-effects of both accidental and deliberate discharges such as fertilizers or pesticides, cannot properly be understood or predicted without thorough studies of the pathways of those materials in the environment, their chemical transformation by interaction with environmental components or through biological action, and their impact on living targets. Because of their complexity, the pathways need examination as a part of analysis of the structure and functioning of ecosystems as a whole. The interaction of pollutants with soils, for example, may be affected by the chemical composition, physical structure, water concentration and composition, absorption capacity, humus content, and the microbial, fungal, and animal populations of the soil. Knowledge of these factors, except for a small number of intensively studied areas is gravely inadequate. Similarly, while there is considerable knowledge about the impact of chemicals on selected living targets, less is known about their impact on ecosystems. Climatic, topographic, hydrological, and edaphic variables combine to alter the significance of a level of exposure of a particular target to a particular pollutant. Even where apparently similar ecosystems are exposed, subtle variations in their structure and dynamic processes may give very different end results. Nonetheless, the basic logic explored by the SCOPE group on ecotoxicology should apply in such pathway studies and in analysing the responses of ecosystems.

2. The Concepts of Ecotoxicology

Ecotoxicology is defined here as follows:

Ecotoxicology is a discipline which studies the impact of toxic agents on ecosystems, in contrast to classical toxicology which deals with the toxic effects of chemicals on individual organisms. It involves the estimation of doses, and the related effects, of any activity which may contaminate the environment. Ecotoxicology uses the results, values, and estimations of classical toxicology and incorporates these into studies of ecosystems.

Some readers may find it difficult to understand or accept the term ecotoxicology. They may prefer to think of it as the study of the total impact of releasing pollutants to the environment. Part of the difficulty arises because toxicological data generally relate to the impact of specified substances on individuals or populations of particular species. The response of an ecosystem is determined by the integration of these effects and is difficult, if not impossible to measure directly.

Impact on human health and well-being is most clearly appreciated, but other living things may be affected and there is an expanding awareness that these non-human effects must be included in the assessment. These effects must be assessed not only locally but on a regional or global scale. It is increasingly accepted that there should be an assessment of not only the acute effects of high doses, but also the late effects of chronic exposure to low levels (including carcinogenesis, mutagenesis, and teratogenesis).

The release of substances to the environment may be intentional, as it is with pesticides, food additives, pharmaceutical products, and antibiotics, which nonetheless have unforeseen side-effects, or unintentional, which is the case with many industrial chemicals. The releases usually occur as a result of man's industrial or commercial activities although some pollutants are released as a result of phenomena with no human involvement. As an example of the latter, some toxic substances (mycotoxins) are produced by fungi which infest food and food grains, and can be a considerable problem in areas with high temperature and humidity.

The pollutants are usually substances that owe their toxicity to their chemical properties or to a content of radioactive atoms.

For the past twenty years the United Nations Scientific Committee on the

Effects of Atomic Radiation (UNSCEAR) has been reporting on releases of radioactive materials to the environment and assessing their long-term effects on man on a global scale. Many of the ideas and techniques developed by that committee, as well as those of the International Commission on Radiological Protection (ICRP), can be applied to assessing the impact of environmental pollution by chemicals. To do this requires consideration of six elements of the problem.

a. Amounts Manufactured and Released

The potential for harm of a given pollutant depends on the amount of it in use. Some information on this subject has been made public, but it is difficult to obtain more for several reasons including ignorance, security (national or economic), or embarrassment.

b. Persistence in the Environment

Substances will have more widespread effects (in both time and space) if they persist for long times without a chemical or physical change which reduces their toxicity. In this context, persistence has been defined as the length of time a substance remains in a recognizable chemical form. Obviously the persistence will depend on how rapidly change takes place after release to the environment. The most common changes result from hydrolysis, oxidation, photochemical reactions, or biochemical reactions in metabolism. In addition to changes that reduce the toxicity one must consider conversion to products that may be more toxic or more persistent; examples are the conversion of DDT to DDE and inorganic mercury to methyl mercury.

c. Transport in the Environment

Since one of the objectives of ecotoxicology is to calculate the exposure of a receptor resulting from unit release of a pollutant, the nature and magnitude of the exposure routes must be known. Meteorological and hydrological phenomena play important roles in transport, particularly in its early stages. Air transport due to winds and diffusion leads to direct exposure of the receptor by inhalation. Air transport coupled with dry surface deposition and wash-out in rain introduces the airborne pollutant into soil, surface waters, and ground water. In soil the pollutant may be retained by adsorption: if it is released into water its transport is chiefly a hydrological process although some of it may escape to the atmosphere and be recycled into the hydrosphere. Information about this geochemical cycling may come from a knowledge of pollutants of geological origin such as heavy metals, oxides of carbon, sulphur, and nitrogen as well as airborne dust particles.

The other important route of environmental transport is through biological processes or food chains. Plants take up chemicals through their leaves and roots while animals absorb them by inhalation or ingestion. Thus the coefficients of absorption by these routes must be quantified. The time of retention in organisms also influences the accumulation; thus a high rate of uptake and a long retention time will result in a bioconcentration of the substance. In addition to these metabolic factors the dietary habits of the receptors must also be known to assess the exposure through food chains.

The number, complexity and interactions of these paths and processes lead to difficulties of conceptualization and overall assessment so that assistance is required from modelling. Mathematical models can assist in selecting critical paths for which simplified calculations are adequate and they can identify the variables with the greatest quantitative importance. These identifications are a useful guide to monitoring and to quantitative studies of critical processes.

d. *Metabolism in the Receptor*

Under this heading are included the intake, uptake, retention, tissue distribution, and metabolism of the pollutant in the receptor. It also includes the basic mathematical formulations for calculating residence times in the critical tissues of the target organism.

The appropriate concepts as well as most of the mathematical procedures and much of the basic data for humans have been assembled by the International Commission on Radiological Protection (ICRP) for calculating radiation doses resulting from the intake of radioactive compounds by 'reference man'. Similar data are required for other organisms that form part of the food chain or are themselves target organisms. These data used by these procedures make it possible to calculate tissue dose rates or integrated doses.

e. *Dose-Effect Relations*

Much basic information about the relative toxicities of different substances to different species can be obtained from classical toxicology which involves laboratory studies of specific effects on homogeneous populations under controlled conditions. One important objective of such studies should be to identify the most appropriate independent variable (dosage) – should it be the amount of toxin administered, the amount retained, or the time integral of concentration in the body or an organ thereof? Plots of the results may often show the familiar sigmoid curve with a threshold, a finite dose with a negligible effect.

These studies must then be extended into the field by epidemiological studies where the populations are not homogeneous and the conditions are not controlled. All effects must be scored and more than one pollutant may contribute to or diminish the observed effect. Under these conditions plots of the results may more frequently approximate a linear dose-effect relation with no threshold. In the event of doubt it may be prudent to assume such a dose-effect relation when calculating risks and acceptable levels of dose for protection of populations against undesirable effects.

In designing dose-effect experiments and surveys, as well as in analysing and presenting the results, use must be made of the most appropriate statistical procedures and probability theory.

f. Assessment of Environmental Impact

The information about environmental persistence and transport coupled with numerical descriptions of metabolism in the receptor permits calculations of dose rates and integrated doses. These will vary from one member of the exposed population to another but estimates may be made of the mean dose to a given population. When the mean dose is multiplied by the estimated risk and the size of the population, the total response can be calculated. Not only must the immediate response be evaluated but also the future response insofar as it is possible. Relevant concepts for this exercise are the dose commitment and harm commitment evolved by UNSCEAR. Setting out to make these integrations into the future ensures that the total effects of pollutant releases will be considered.

It would be useful to identify observations and measurements of environmental variables that could be made to check the numerical predictions; for this it is desirable to identify accumulator and indicator organisms. Whether it is possible to identify environmental variables appropriate to a large number of pollutants appears doubtful, but many specific examples can be found and from a collection of these some general principles may emerge.

To illustrate by example what is meant by 'ecotoxicology', there is provided in Appendix D a summary of the ecotoxicology of methyl mercury; it indicates what information is required and demonstrates how it may be used. The summary shows that in practice there are two critical paths leading to an intake of methyl mercury by receptors:

(i) Methyl mercury contamination of food (usually grain).

(ii) The entry of inorganic mercury into a body of water.

Path (i), which is direct and simple, has led to the poisoning of seed-eating birds, domestic animals, and man from eating cereal grain dressed with organic mercury compounds. Knowing the concentration in the grain and the amount of grain eaten per day, one can calculate from the retention equation for methyl mercury in the receptor, the body content at any time following the beginning of consumption, as is done for internal radioactive contamination. The correlation of these body and tissue contents with neurological symptoms permits the construction of dose-effect curves followed by the calculation of risks and maximum permissible levels.

Path (ii) is more complex and correspondingly more difficult to evaluate. As Figure 17 shows, the most important chain of events, following the contamination of a body of water with inorganic mercury, comprises the following steps:

(1) Deposition of inorganic mercury in the bottom sediments.

(2) Conversion of inorganic mercury to methyl mercury by the action of microorganisms.

(3) Release of methyl mercury to the water.

(4) Uptake of methyl mercury by fish:

  (a) directly from the water through the gills;

  (b) indirectly through food (plant or animal) that has already taken up methyl mercury.

(5) Selective concentration of methyl mercury by metabolic processes in the fish.

(6) Eating of the contaminated fish by man or other receptors.

The most important link in this chain is step 2, and, unfortunately, it is the least well known quantitatively. This difficulty is aggravated by the near impossibility of measuring the very low concentrations of methyl mercury which occur in natural waters. Otherwise realistic calculations of the accumulation of methyl mercury in fish are feasible. Knowing this the accumulation of methyl mercury in the eater of the fish can be calculated in the same manner as for path (i).

In canvassing the steps involved in an ecotoxicological study, as illustrated in Appendix D, it should be recognized that the information available on methyl mercury is superior to that in hand for most other toxic substances.

g. *Analysis*

Basic to studies of ecotoxicology (and monitoring) are the feasibility and reliability of analysis for pollutants and pollutant residues in environmental media. In fact, doses cannot be determined without adequate analytical methods. This was recognized very early in the development of the programme of SCOPE, and a working party under the chairmanship of W. Gallay was set up to study and report on this problem.

A small group of experts was gathered to consider the merits and drawbacks of various existing methods of analysis for each of the many pollutants involved. The report of the working party was published as SCOPE 6, 'Analytical Methods for Selected Pollutants' (SCOPE 1975b). Where possible, in addition to a sophisticated method requiring expensive equipment and highly trained analysts, a simple method yielding adequate precision and accuracy was also included. Where feasible, methods were chosen for a pollutant in air, water, and biological media. It is expected that further work in this field will continue with the addition of further pollutants, and possible revision of the methods already published.

E. ECOSYSTEM PROCESSES

As Chapter 1 states, the ecosystems of the world have been modified extensively by man over the past million years and this alteration has in turn affected the interplay between the world's flora and fauna and the non-living environment. Because many of the features of that non-living environment, including the composition of the atmosphere, the structure and chemistry of the soil, and the levels and cycles of many elements and compounds, are the product of life and are vastly different from the situation on the lifeless earth, man's recent modification of the world's ecology carries with it the potential to perturb these features and processes. Whether or not this is a real problem is less easy to state and depends on critical, quantitative analysis of the composition and dynamics of ecosystems and of the degree of their modification by man.

There is urgent need for a practicable and quantitative approach to ecosystem dynamics in order to give more precision to this analysis and to provide a better basis for predicting trends. The ICSU-sponsored International Biological Programme (IBP) provided a great stimulus to the study of ecosystem structure and function and developed a firm basis for further ecological research.

Because ecosystems traditionally utilized for agriculture are now being intensively studied by FAO and many governmental, non-governmental, international, and national organizations, SCOPE has given special attention to managed natural systems. These have received relatively little attention, yet when they are utilized by man they tend to become rapidly destabilized, with associated severe, and sometimes essentially irreversible changes in their physico-chemical environmental attributes and in their biological characteristics. Considerable interest has been expressed in this subject by UNESCO, whose 'Man and the Biosphere' (MAB) programme contains a number of projects related to developing a better understanding of natural ecosystems, and a sounder scientific basis for their long-term management. SCOPE joined with the MAB programme in an evaluation of present knowledge of the patterns of change which occur in terrestrial ecosystems, and of the way in which this knowledge could be applied to the management of natural ecosystems (Chapter 5 and Appendix C).

The processes of ecological succession involve the sequential change in the species occupying a particular site. There is a close link with the evolutionary processes which continually modify the genetic constitution of the organisms involved in these ecological dynamics. Like successional processes, genetic evolution has been modified by man. Modern cultivars are selected lines with a very narrow genetic base, raised in environments whose inherent seasonal variation in soil moisture, nutrient levels, and competitive pressures is further reduced by management. Today, selective plant and animal breeding is being speeded up as the need for enhanced productivity in continually changing agricultural situations mounts. This effort needs, however, to draw on a large pool of genetic variability, much of it in natural or semi-natural habitats where the wild relatives of cultivated plants and domestic livestock survive or in areas where agriculture continues to use primitive, obsolete, or special genetic stocks. SCOPE has not concerned itself directly with these vital issues because they are the object of a major FAO programme, MAB Project 8, and activities supported by IUCN and UNEP, but research drawing upon ICSU expertise will certainly continue to be necessary, and as such, finds its place in Chapters 5 and 6.

The understanding of both successional processes and genetic conservation is important to the management of arid lands under rapid transformation by irrigation and drainage. In these situations the changes are rapid and massive. This process forms the theme of Section 2 of this chapter, and is examined as an example of drastic alterations by intensive management of soil and water.

1. The Analysis and Modelling of Successional Change

a. Present Concepts Regarding Ecological Succession

Classical concepts of ecological succession involve two key assumptions:

(1) that species replacement during succession occurs because populations tend to modify the environment, making conditions less favourable for their own persistence and leading to progressive substitutions, and

(2) that a terminal stabilized system, the climax, finally appears and is self-perpetuating, in equilibrium with the physical and biotic environment.

This view of ecological succession, based largely on observed spatial vegetational zonation which had occurred over centuries, and on patterns of revegetation on abandoned farmland, has been generally accepted by the ecological community following the pioneer studies of Clements and others even though obvious exceptions to it exist. Tansley (1935) and others indicated in general terms while Egler (1954) suggested more formally that the classical model of succession may not apply in all situations. Egler referred to the classical model as 'relay floristics' and suggested that, in many cases, the 'initial floristic composition' following a perturbation may dominate the entire pattern of succession; that is, unless species persisted through the perturbation, or were able to enter the perturbed site shortly afterwards, they would not be represented in the community that developed.

Evidence has gradually accumulated to suggest that the initial floristic composition concept may have much wider applicability than envisaged by Egler (Colinvaux 1973, Drury and Nisbet 1973, Horn 1974). Recently, Connell and Slatyer (1976) proposed an overall system of successional processes which incorporates the possibility of both the relay floristics and initial floristic composition pathways operating independently or in combination, and in addition includes a pathway in which succession is truncated short of the expected climax composition. These modifications clearly make the successional concepts more useful in understanding the properties of managed ecosystems, especially those being held in something akin to a 'steady state' and being managed for a sustained yield.

In Figure 11, various pathways are clearly indicated, and likely effects of perturbation, at different stages in each pathway, are also shown. The basic dichotomy between the classical 'relay floristics' concept (pathway 1) and the other models (pathways 2 and 3) is reflected in the immediate divergence of the pathways. In Model 1, referred to by Connell and Slatyer as the 'facilitation' model, the classical replacement pattern occurs, successive suites of species which

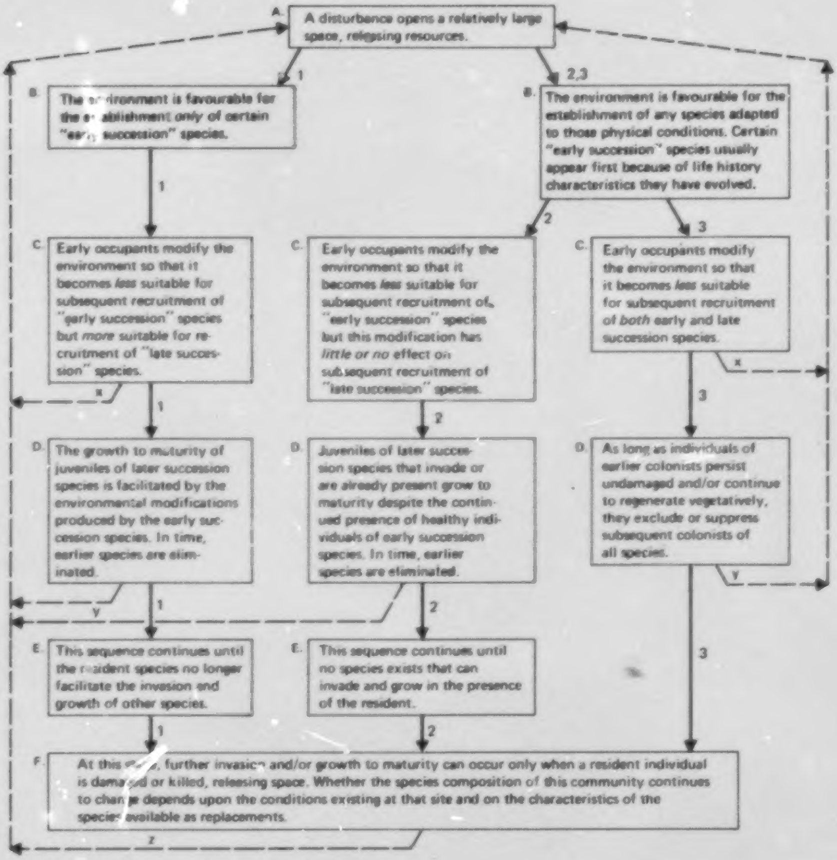
A. A disturbance opens a relatively large space, releasing resources.
1
2,3
B. The environment is favourable for the establishment *only* of certain "early succession" species.
B. The environment is favourable for the establishment of any species adapted to those physical conditions. Certain "early succession" species usually appear first because of life history characteristics they have evolved.
1
2
3
C. Early occupants modify the environment so that it becomes *less* suitable for subsequent recruitment of "early succession" species but *more* suitable for recruitment of "late succession" species.
C. Early occupants modify the environment so that it becomes *less* suitable for subsequent recruitment of "early succession" species but this modification has *little or no* effect on subsequent recruitment of "late succession" species.
C. Early occupants modify the environment so that it becomes *less* suitable for subsequent recruitment of *both* early and late succession species.
x
1
2
3
x
D. The growth to maturity of juveniles of later succession species is facilitated by the environmental modifications produced by the early succession species. In time, earlier species are eliminated.
D. Juveniles of later succession species that invade or are already present grow to maturity despite the continued presence of healthy individuals of early succession species. In time, earlier species are eliminated.
D. As long as individuals of earlier colonists persist undamaged and/or continue to regenerate vegetatively, they exclude or suppress subsequent colonists of all species.
y
1
2
y
3
E. This sequence continues until the resident species no longer facilitate the invasion and growth of other species.
E. This sequence continues until no species exists that can invade and grow in the presence of the resident.
1
2
F. At this stage, further invasion and/or growth to maturity can occur only when a resident individual is damaged or killed, releasing space. Whether the species composition of this community continues to change depends upon the conditions existing at that site and on the characteristics of the species available as replacements.
z

Figure 11 Three models of the mechanisms producing the sequence of species in succession. The dashed lines represent interruptions of the process, in decreasing frequency in the order x, y, and z. Pathway 1 is referred to as the 'facilitation' model; pathway 2 as the 'tolerance' model, and pathway 3 as the 'inhibition' model (from Connell and Slatyer 1976)

occupy the site tending to make the environment less favourable for their own existence and more favourable for their successors to invade and grow to maturity. In Model 2, the 'tolerance' model, environmental modifications induced by early colonists may neither increase nor decrease the rates of recruitment and growth to maturity of later species. The latter appear later because they either arrived later or, if present directly after the perturbation, had their germination inhibited or their growth suppressed. In contrast to the 'facilitation' model, in Model 3, termed the 'inhibition' model, the early occupants rather than facilitating progressive occupancy by other species, inhibit the invasion of other species either by pre-empting available space through physical occupancy alone, by physical competition, the use of allelopathic substances, or other effective means. This inhibition has the effect of truncating the succession at a stage that would generally be regarded as being dominated by non-climax species such as shrubs rather than trees (Niering and Goodwin 1974). Later succession species may only be able to enter the site when the inhibitory species are damaged or killed. If this occurs during a subsequent pertubation, the new succession may well follow a different pathway, avoiding a repetition of successional truncation.

In essence, the Connell and Slatyer concepts are based on the premise that the presence of a particular species in a community is dependent on the product of two probabilities; the first being the probability of a propagule being available at a site – a function of the ability to survive a perturbation or to reach the site by appropriate dispersal mechanisms; and the second being the probability of the propagule being able to become established at the site – a function of the environmental requirements of the species, its adaptive ability, and its reproductive strategies in relation to the prevailing environment.

The factors determining these probabilities are influenced by the size of the area perturbed and the frequency and severity of the perturbation, but propagule availability, in particular, is increasingly dependent on dispersal characteristics as both the area and severity of the perturbation increases. By comparison, establishment and/or persistence of a propagule is more related to degree of perturbation than to area. Plant species differ widely in their ability to persist as seeds, in their ability to become established or persist in exposed or protected locations, and in their competitive ability to obtain water and nutrients.

Just which of the available species are successful as colonizers, as invaders, or as dominants in various stages following perturbation will therefore depend on their adaptation to the physico-chemical site characteristics, on their competitive and other interactions with the other species in the community, and on their own life-history characteristics. There is, however, now significant evidence indicating how each model might operate, and how different pathways might be followed depending on the intensity, frequency, and scale (in terms of area) of a particular perturbation. The model also incorporates the concept of truncated succession, a phenomenon that many ecologists have observed but which has seldom been explicitly included in any general conceptual framework for succession as a whole. Overall, this general framework appears a useful basis for viewing successional processes, and one which lends itself to the development and use of mathematical models of successional processes.

b. Methods Available for Modelling and Predicting Successional Patterns

In recent years the application of several powerful modelling procedures to ecological processes has stimulated research into ecological succession in general, into the underlying processes involved in succession, and into the possibilities of providing a sounder ecological basis for the development of management strategies for natural and near-natural ecosystems.

Amongst these procedures, those involving the application of Markov processes to problems of ecological succession (Waggoner and Stephens 1970, Horn 1976) have stimulated most interest because a number of successional sequences appear to provide the ingredients for first-order Markov models and such models have desirable attributes for ecological studies and for management purposes.

A Markov process is one in which the future development of a system is determined by the present state of the system and is independent of the way in which that state has developed. A first-order Markov chain comprises a two-dimensional matrix (transition matrix) in which certain values of input parameters are converted to output values using specified probabilities (transition probabilities).

For example, Markov models are relatively easy to derive (or infer) from successional data, and the presence of the Markov property can be tested explicitly. Secondly, the models do not require deep insight into the mechanisms of dynamic changes, but can help to pinpoint areas where such insight would be valuable and hence act as both a guide and stimulant to further research. Thirdly, the basic transition matrix, which is the effective core of the models, summarizes the essential parameters of dynamic change in a system in a way which few other model families can achieve. Fourthly, the results of the analysis of Markov models are readily adaptable to cartographic presentation, and, in this form, are frequently more readily presented to, and understood by, resource managers. Finally, the computational requirements of Markov models are modest, and can easily be handled on small computers, or, for small numbers of states, on hand calculators.

In addition to these features, several interesting analyses of the models can be conducted which provide important information for the functionally oriented ecologist, and to the ecosystem manager. For example, analysis of the transition matrix leads to estimates of the time over which each successional stage can be expected to persist; the time to reach a climax composition, and the likelihood of the succession being truncated at a composition which would traditionally be regarded as sub-climax. All of these attributes are of direct relevance to ecosystem structure and function and to management strategies.

There are also a number of disadvantages to the use of Markov models in ecological succession. In particular, departures from the simple assumptions of stationary, first-order Markov chains, while conceptually possible, make for disproportionate degrees of difficulty in analysis and computation. Also, the complete data sets necessary for the construction of transition matrices, and for subsequent validation of the models, are seldom available, so recourse must be made to other procedures to obtain the necessary information. There is also the concern of the functionally-oriented ecologist that a relatively coarse Markovian transition matrix, with its strongly stochastic character, may mask a number of key ecological processes.

The first of these problems may limit the application of Markovian models to a greater extent than is foreseen at the present time, but, until more models are developed and tested, the degree to which successional sequences conform to the requirements of stationary, first-order chains cannot be predicted. The second problem is very real for ecological systems containing long-lived organisms, since historical records are relatively short.

It is largely for these reasons that functional types of models, sometimes referred to as stand models (Leak 1970, Botkin and Miller 1974) have also created wide interest. The major advantage of such models is that they do not require long historical data records for parameter estimation, using instead basic physiological attributes of the species under consideration, which can often be inferred if not available from direct observation. Furthermore, the output from the model can be applied to a number of transformations and interpretations, so that the model user can present output in the same fashion that he would use actual data. Indeed, the model lends itself to experiments which could include management questions related to harvesting and grazing frequency, fertilizer addition, and related practices. This has implications of direct value to management.

However, testing of these models still presents difficulties, and a major disadvantage is that they use a great deal of computer time. Indeed, they represent a quantum leap in computer use in ecology, generating computer hardware problems in all but the most advanced computer centres.

Other procedures include the use of multi-variate analysis (Austin 1972) and of ordinary linear differential equations (Shugart et al 1973), each of which has particular advantages when applied to particular problems.

The advantages of the straightforward Markov model, particularly in relation to computer requirements, are such that its application to studies of ecological succession warrants detailed examination and exploration. The main obstacle in proceeding rapidly with a Markovian model is likely to be the absence of comprehensive data sets with which to construct the transition matrices. Other techniques, perhaps stand models in particular, may be used to generate the necessary data for the transition matrices, thereby reducing the amount of computer capacity and time associated with the sole use of a stand model, and enabling the construction of a Markovian model with its attendant attributes, but with desirable functional elements implicitly included.

c. *Application to Management of Natural and Near-natural Ecological Systems*

From the foregoing it is evident that the effective application of ecological knowledge to problems of ecosystem management requires the utilization of a variety of information – ranging from historical records through basic ecological research, to data from management – and also requires a high degree of interaction between the ecologist and the manager. In turn the ecologist interacts with a variety of other specialists, particularly in experimental design and interpretation, model building, and validation; and the manager interacts with those who influence his selection of management goals and constrain his management strategies.

In Figure 12 a general scheme, identifying the role of the ecologist, both in his specialist activities, and as an adviser to management, is depicted. Following the formulation of management aims, the first step for the ecologist is to assemble all available information on the system under study and on ecologically relevant systems elsewhere, including basic descriptive information as well as the effects of various management practices where these have been documented. Experiments may have been conducted in the region, and there may be a fund of anecdotal

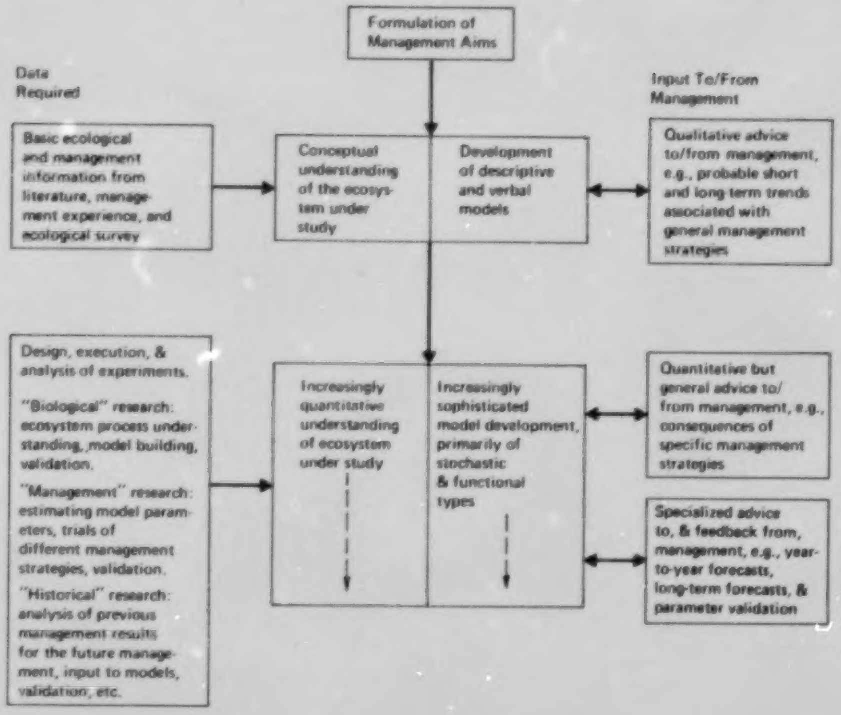
Formulation of Management Aims
Data Required
Input To/From Management
Basic ecological and management information from literature, management experience, and ecological survey
Conceptual understanding of the ecosystem under study
Development of descriptive and verbal models
Qualitative advice to/from management, e.g., probable short and long term trends associated with general management strategies
Design, execution, & analysis of experiments.
"Biological" research: ecosystem process understanding, model building, validation.
"Management" research: estimating model parameters, trials of different management strategies, validation.
"Historical" research: analysis of previous management results for the future management, input to models, validation, etc.
Increasingly quantitative understanding of ecosystem under study
Increasingly sophisticated model development, primarily of stochastic & functional types
Quantitative but general advice to/from management, e.g., consequences of specific management strategies
Specialized advice to, & feedback from, management, e.g., year-to-year forecasts, long-term forecasts, & parameter validation

Figure 12 A schematic representation of the role of ecologists in producing ecosystem models and in giving advice for management purposes

information. To use such local background information is usually much more effective, in a benefit-cost context and because time is usually an important consideration, than to collect similar information afresh.

At this stage, a simple model can usually be built which incorporates existing information about the components of the system, and predicts the variables (such as wood production, meat production, or maintenance of a cerain series of desirable species) in the objective function defined by the manager. The best use should be made of the manager's own experience, and existing knowledge about the behaviour of ecosystem components should be assembled from local literature and local experts. This quick model may take the form of a transition matrix of vegetation types where the transition probabilities can be defined, or of a functional model of each type separately. In either case, attempts should be made to associate error estimates with the model inputs, and hence with the outputs. With this model, the manager may then proceed to estimate the short-term effects of the different practices he is considering, in terms of the selected objectives, and choose that practice which tends on average to move the objective function in the desired direction.

If the model is in the form of a transition matrix, the objective function will need to be rephrased in terms of desirable mixes of successional stages, including perhaps their spatial configuration in the area. A functional model, if that seems most appropriate, may often be simplified by assuming that direct species to species interactions among the plants may be ignored as a first approximation, and that each species may be modelled as being influenced by, and influencing, its abiotic environment.

This quick model, apart from the estimates derived from general regional background information, may also require information about the initial state of the system. In the case of the transition matrix type of model, this may be satisfied by the area of each successional stage. In a functional type of model, more detailed information about each of the vegetation types present may be called for.

It is not suggested that a model of this sort should be used for more than short-term prediction. The manager may act on the assumption that it is reliable (particularly where no more direct information is available), but must remain alert for error, monitoring the actual effects of the practices on the ecosystems in question. Then, by providing new inputs to the model, and obtaining a set of new predictions, he can modify his management strategy by trial and error to optimize his objective function. In other words, management should proceed interactively with the model.

The degree to which this initial quick model should be improved will depend on how important longer-term predictions are, and what resources are available. Additional sophistication of the model itself, its conceptual formulation and implementation, may need relatively little effort, compared with the collection of the extra data needed. To estimate new parameters for a model may call for considerable resources, and such an effort may only be justified by the need for a sound long-term management strategy. In any case, a first step will be to conduct sensitivity tests on the initial model to determine where the benefits of improved precision, from the point of view of the objective function, will justify the effort and resources required.

Apart from the building of the improved model and the collection of additional data, validation is also a problem. Since, by its nature, the model is at least in part new, this will need to be done afresh, preferably by new observations within the management area – observations, of course, which should not be associated with those used to estimate the parameters of the model. Validation will add to the time for model development, and again emphasizes the fact that ad hoc development of a sophisticated model will be worthwhile only if much hangs on it, and if long-term predictions are needed. If the validation can be replicated, it will have the advantage of providing unbiased error estimates for the model predictions.

It is clear that, if an analogous situation has already been modelled, a great deal of time and effort can be saved by adopting an existing model. However, a warning must be sounded. Unless that model has parameter estimates derived from similar material, and unless it has been validated for systems covering the same range, to accept its predictions will be an act of faith. It may be better to establish new, replicated, validation tests within the management area, and to use the predictions only after validation is achieved.

d. Conclusions and Recommendations

A full list of conclusions and recommendations is given in the main report of the MAB/SCOPE Workshop. The main conclusions at this stage are:

(i) Rapid advances have been made in recent years in both theory and experiment in the general level of understanding of ecological succession. In particular, a much better appreciation now appears to exist of the interplay between different successional patterns, the effect of perturbations on the observed patterns, and on the phenomenon of successional truncation in which long-term site dominance is achieved by species which might normally be assumed to be early succession, sub-dominant species.

(ii) Knowledge of successional patterns can provide a useful basis for developing models of direct relevance to the management of natural communities such as forests, rangelands, and lands set aside as biosphere reserves. Conversely, patterns of natural succession are of very limited relevance to the problems of managing ecosystems in which human intervention has markedly altered the physico-chemical environment and the biological species composition.

(iii) A veriety of techniques are available for modelling purposes. Of the techniques with stochastic properties, Markov models have been used successfully in several studies and appear to offer considerable scope for development and application. Of the techniques based on functional attributes, stand models which permit simulation of primary stand attributes also have considerable potential. However, no single approach can be generally recommended and all techniques have disadvantages which preclude their use in different situations.

(iv) Effective contributions to management require interaction between ecologists and managers. In turn, it is essential that the ecologist interacts with a variety of other specialists, particularly in experimental design, data interpretation, model building, and model validation; and the manager interacts with those individuals and agencies that influence his selection of management goals and constrain his management strategies.

The main recommendations at this stage are:

(i) Further work on ecological succession should be encouraged with a view to providing a thorough understanding of successional dynamics, and the interrelationship between successional processes and other community attributes associated with stability, diversity, dominance, and resilience. In particular, more information is needed about the biological processes associated with truncated succession, and its associated characteristics.

(ii) A 'Practitioner's Manual' should be prepared which outlines the techniques available for modelling successional processes, the data requirements and limitations of each of the major techniques, and methods of applying these to both ecological processes and to questions of management of near-natural communities.

Specific studies of selected ecosystems should be conducted with a view to providing the data necessary for the construction of comprehensive ecological and management models. Ideally, these studies should be conducted on sites where most of the key ingredients for model construction are already available. In this regard, knowledge of the effects of specific perturbations is an important factor. Because of the widespread occurrence of fire in nature, its importance as a natural and induced source of perturbation and its use in management, an in-depth study of the role of fire in ecological systems warrants high priority in future programmes.

2. Irrigation and Drainage of Arid Lands

In contrast to the slow succession of plant and animal populations in managed natural systems, the transformations brought about by irrigation and drainage in arid lands are abrupt and sweeping. On the whole, they are better understood than the dynamic effects of perturbations in grass and forest lands. Nevertheless, the translation into practical action of scientific knowledge of water use efficiency and of biological and hydrological processes in irrigated soils lags far behind research findings. Because of the vital part played by irrigation in providing the world's food supply, it is a matter of urgency that the growing knowledge of these transformations and of their impacts upon other resource use and upon human health and welfare be applied promptly and widely.

Like the analysis of successional changes, the scientific management of irrigated lands calls for close collaboration between research workers and decision-makers. It also requires a degree of integration among scientists of many disciplines – agronomy, ecology, genetics, geography, geology, hydrology, public health, and engineering – that rarely is attained.

These problems, which are recognized as of major importance under the MAB programme, led to the convening of a symposium in Alexandria in February 1976 under the auspices of the Scientific Committee on Water Research (COWAR) in collaboration with the United Nations Environment Programme (UNEP) and the Egyptian Academy of Scientific Research and Technology. SCOPE joined with MAB and COWAR in organizing a joint working group which analysed the evidence presented and prepared a report (see Chapter 5 and Appendix C) from which a summary is presented here.

a. Irrigation and World Food

In the face of a consensus that supplying food for a prospective population will require by 1985 an increase in cereals production alone of at least 30 percent over

1970, major revisions in systems for food production, storage, transport, distribution, and consumption are a necessity. Production improvement can be achieved by increasing yields on existing lands or by expanding the total area of land. Both approaches probably must be adopted simultaneously. Recent experience with the 'green revolution' provides startling examples of the need for an integrated approach in order to achieve substantial yield increases: new seed and old production practices usually result in failure. New seed requires modified planting procedures, proper fertilization, improved irrigation, and new pest control practices as well as changes in harvesting and storage procedures and facilities.

Irrigation is one means of improving the total volume or reliability of agricultural production by managing water. Water control is of significance in effecting the returns from additional inputs of fertilizers, seed, diversification, mechanization, and other management efforts. In Asia, for example, water control, linked with other inputs, may account for a fivefold difference in the yields of rice per hectare. This excludes the volume of rice yield that may be obtained where fully effective practices are employed in a farm demonstration plot or research station. It is common, in India as well as in Pakistan, to find that while the average yield for rice may be of the order of 1.6 tons per hectare, yields twice that amount will be obtained in farm demonstration plots, and research stations may report three to six times that volume.

It is estimated that about 13 percent of the world's arable lands are irrigated, and that they use about 1.4×10^{12} cubic meters of water per year. The irrigated harvested area in developing countries is estimated to increase at about 2.9 percent per year while nonirrigated arable land has been increasing at a rate of only 0.7 percent per year (Holy 1971). To the extent that food problems are to be met by enlarged production the enhancement of irrigation is important. As a minimum it is essential to maintain the present productivity of irrigated land.

b. Physical Water Efficiency in Crop Production

It is evident that irrigated agriculture in combination with other inputs can show enormous increases in crop yields. The improvement of such practices on existing land is more attractive than the irrigation of additional land because the maintenance and improvement of existing projects is less than one third the cost of bringing new land into cultivation. The possible significance of such improvements is suggested by the estimate that if, for irrigated cereal crops on approximately 70 million hectares, an average increase of only one ton per hectare per year were achieved by improved methods, it would mean an increased production of 70 million tons or nearly 20 percent of the total estimated annual cereal output of the developing countries.

It is estimated that about 80 percent of the water consumed by man is for crop production. There is a limit to potential supplies. Of the total volume of water on the earth's crust about 95.5 percent is saline water in the oceans and another 2.2 percent is imprisoned in the ice caps and glaciers. For all practical purposes the volume of water annually available for use is provided by precipitation on the earth's surface and only about 3 percent of the total supplies of the freshwater in the hydrosphere can be marshalled economically for man's activity. Irrigation diverts water from surface or ground supplies to soils where moisture is deficient for crop growth.

The physical crop producing efficiency of water is normally expressed as the ratio between the quantity of water effectively used by the plants in crop production or lost in soil leaching and the total quantity of water supplied from the source.

It may be thought of as r = yield/water taken from the source in which r is the physical efficiency. The economic efficiency of the water as gauged by its incremental value in relation to incremental cost is another measure. In fact physical efficiency ratio should be divided into two parts, r_1 and r_2, with:

$$r = r_1 \times r_2 : r_1 = \frac{\text{yield}}{\text{water retained in the unsaturated root zone}}$$

$$r_2 = \frac{\text{water retained in the root zone}}{\text{water taken from the source}}$$

It is customary to estimate the physical efficiency of water use in terms of a total project, the distribution of water to fields, or the efficiency on an individual farm. Physical efficiencies commonly range from 25 to 50 percent (Figure 13). To

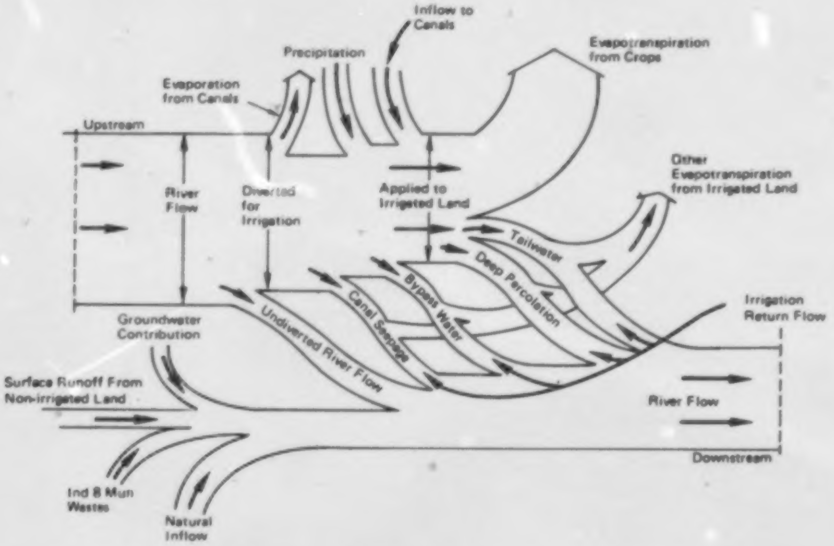

Figure 13 Model of the irrigation return flow system. Source: Hotes and Pearson (1976) (Alexandria Symposium)

understand losses that are reflected in these ratios it is essential to trace out the processes at work in distribution of water and its use by plants in the unsaturated zone (Figure 14) and to appraise what effective and economic measures can minimize them. The amount of irrigation application (J_s) which is not consumed by evaporation (E_s) or plant transpiration (T_s) moves to the saturated zone (J_w) where it moves laterally (O), accumulates causing the water table to rise, or contributes to later evaporation (E_g) and transportation (T_g). The movements are influenced by water application, soil texture, ground water storage, crop, and cropping practice.

Some of the means available for reducing water losses include controlling water flow by storage, reduction of evaporation, improvements in conveyance systems, changes in distribution systems, refinement of field application methods, selection of crops, and breeding of crops for characteristics suited to water conservation. Many limiting factors may arise in cropping, and it is known the response of a crop to water supply depends upon its stage of growth.

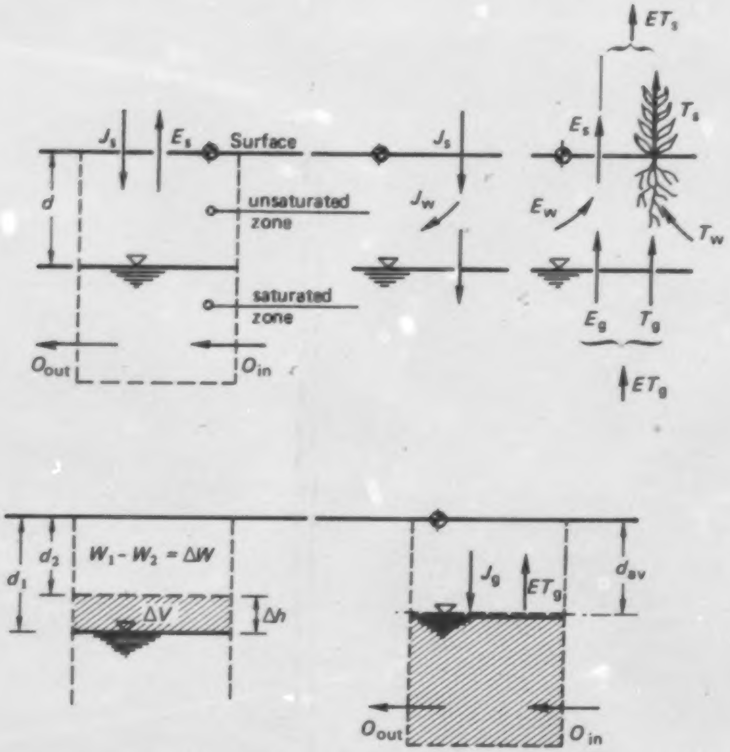

Figure 14 Distribution and movement of water in the ground. Source: Peczely (1976)

c. *Water and Salt Balance in the Root Zone*

The ultimate goal of water control is to regulate the moisture content of the unsaturated root zone according to the requirement of the crop. The unsaturated zone is, however, a key part of the hydrologic cycle. It is in that thin area between soil surface and the top of the saturated ground water area that water seeps down to the ground water table, moves back into the atmosphere through evaporation or transpiration by plants, or moves laterally into adjoining areas. As a result of changes in the movement of the moisture in the root zone microclimate may be altered, surface runoff may be changed, ground water regime may be modified, and the quality of water in the zone and in associated ground water storage may be changed.

Fundamental to the use of water by plants is the migration of salts in the soil. Where the water table is below a critical level the resultant vertical movement of capillary water in the layers overlying the water table is directed downwards. Infiltrating precipitation leaches as soluble salts flow from the upper levels. Evaporation of ground water rising by capillarity brings soluble salts back toward the soil surface.

A number of water-salt balance equations have been proposed by different authors. One of the simplest forms of the equation for inflow and outflow of salt is the following (Kovda 1976):

$$YC + Q_1C_1 = Q_2C_2 + Q_{dr}C_{dr}$$

Y – amount of irrigation water inflow during a given time period,

C – concentration of salts in irrigation water during a given time period,

Q_1 & Q_2 – natural flow rate of the incoming and outflowing ground water respectively,

C_1 & C_2 – concentration of salts of the incoming and outflowing ground water respectively,

Q_{dr} – the flow rate of the outflowing drainage water,

C_{dr} – the weighted average of the actual salinity of the drainage water.

Basic concepts of soil water-salt balance have been developed to show the sources, distribution, chemical composition, and total amounts of various salts as well as the dynamics of salinization in the soil and in the water used for irrigation and ground water within the irrigated area. This makes it possible to estimate possible changes in the water-salt balance in the area from the beginning of irrigation through the various stages of continued operations, and to determine the point at which a steady water-salt balance is established. It is also practicable to estimate optimum salt concentrations, the optimal and critical depth of the water table, and the most effective irrigation and leaching regimes where the latter is required (Kovda 1976). The main factor in the regulation of salt balance is effective drainage of saline ground water.

The physiological toxic limit of salt concentrations of water in the root zone lies near 10 to 12 grams/liter if the salt composition is chloride sulphate. Water with mineralization of up to 2 to 3 and even 5 to 7 grams/liter can be used for irrigation under favourable drainage conditions. However, the increase of salt concentration in irrigation drainage water will lead to a drastic increase of the drainage water outflow from the irrigation system. Several factors must be taken into account when judging the safe quality of irrigation water: nature and amount of salts in water, nature and texture of the soil, conditions of natural and artificial drainage, depths of the ground water, and the characteristic of the water-salt balance.

Land under irrigation may deteriorate through a rise in the ground waters causing water logging, through salinization (whether due to high salinity of the ground water or the dissolving of salts in the root zone by the rising ground water), and alkalinization. Especially difficult problems arise in the case of secondary soda salinization (alkalinization). The mechanisms of oversaturation of plant organs by nonorganic toxic salts are not fully understood, but it is clear that there is no direct relationship between absorption intensity of water and salts by plants, that the intensity of salt absorption is regulated by tissue permeability, and that plant metabolism has an effect on salt absorption.

It is possible to cope with soil deterioration through increasing the efficiency of the irrigation network, reducing infiltration loss in irrigation canals, construction of drainage or pumps in order to maintain deep ground waters, deep horizontal drainage, leaching waterings, and well-equipped water distribution systems. Principal ways of dealing with soda salinization include limitation of water supply, improved efficiency of irrigation systems, and removal of alkaline ground waters by drainage. Soil alkalinization can be ameliorated by gypsum or sulphur application. The proper balance of these various measures in any area depends upon the local circumstances. There rarely is a single solution: the suitable mix of action must be adjusted to physical, biological, economic and social constraints.

Semi-arid areas also require a very careful control of water application to prevent either salinization or wasteful use of water. Under present day conditions irrigation water is supplied mainly through piped networks. Water rations must be carefully linked to conditions of local climate and soil and to the specific crops grown to assure a complete uptake of the water applied by the crop without excess water remaining in the soil. To achieve maximum efficiency in water utilization by minimizing evaporation losses, modern techniques of trickle irrigation may be preferable in some situations to sprinklers or irrigation canals. The higher investment for initial installation is quickly regained by economy in water use.

It is estimated that every year several hundred thousand hectares of irrigated land fall out of cultivation as a result of salinization (Kovda 1976). FAO data suggests that no less than one-half of the irrigated area of the world is subject to salinization and is experiencing reduction in crop production as a consequence. In the Eastern Mediterranean region the percentage of salt-affected or water-logged soils amounts to about 50 percent of the total irrigated area in Iraq, 23 percent in Pakistan, 50 percent in Syria, 30 percent in Egypt, 15 per cent in Iran, and about 80 percent in Punjabi sections in Pakistan.

Although increasing salinity in irrigated soils is virtually a world-wide phenomenon, there are successful examples of preventing soil deterioration and of actual improvement of originally saline lands (Dukhovny 1975). No accurate balance has been drawn for the world as a whole, but the rate of deterioration is known to be relatively rapid and widespread. In some areas land abandonment equals the rate at which new land is brought under cultivation.

The direct result of the prevailing methods of irrigation and drainage design and operation in many areas is to so alter the water-salt balance in unsaturated zones of the soil as to impair crop production. In some places this is a long, slow process of decades, in others it may begin in a few years, especially if inadequate provision was made for drainage.

d. *Other Impacts*

In addition to its effects on immediate crop-producing capacity of the land, irrigation is part of a complex of practices comprising management of available water resources, controlled distribution of water over cultivated lands, and withdrawal of excessive water through drainage. Both the quantity and quality of downstream flows are affected. Ecological consequences of this complex include creation of new ecological systems related to water bodies, and radical modification of the terrestrial habitat. Some of the ecological changes are from ephemeral to perennial situations, as in the case of water bodies which formerly were ephemeral features following cloud burst rainfall and are converted into man-made lakes, irrigation drainage ditches, and the like.

Other ecological changes are related to intensive management. The subhumid and arid ecosystems are inherently unstable and exhibit potential for dramatic changes triggered by a sudden appearance of extensive areas of irrigated crops. These foster outbreaks in insect or bird population, and in flora. Arid ecosystems have limited capacity to assimilate, withstand, and respond to inputs of water, chemicals, and energy that are associated with intensive management of irrigation farms. These lead to alterations in species diversity, numbers of organisms, and the stability of their interrelationships. Aquatic organisms are most affected, but the adjoining terrestrial ecosystems may be profoundly influenced by changes in soil fauna, soil microflora, animal life, and weed flora and by the stimulation of new modes of land use in the agro-rural complex. The new agroecosystem initiates a series of secondary successional changes. Gradual buildups or sudden outbreaks of weeds or animal pests may occur as a result of species attributes and interaction.

The modification of aquatic ecosystems through irrigation practices results in a shift in humidity and sedimentation, in nutrient concentration and transport and resultant eutrophication of fresh waters, in wide distribution of pesticides and herbicides, in dissemination of aquatic weeds and phreatophytic plants, and in bacterial and viral contamination and spread of parasite vectors. It is now well established that although irrigation may have a long series of beneficial effects upon human health by improving nutrition, establishing adequate water supply and waste disposal facilities, and organizing more suitable community facilities, it also has deleterious effects through chemical pollution and through the distribution of diseases such as malaria and schistosomiasis.

e. Conclusions and Recommendations

As human interventions in arid land ecosystems become more widespread and complex the need increases to understand the physical, biological, and social processes which they trigger or interrupt. In a broad sense any research which increases understanding of these processes will increase the capacity of people on the land to deal more effectively with possible environmental effects from irrigation and drainage. Nothing short of a long-term programme on an international scale will bring answers to a whole array of questions which have been identified. However, the most urgent need is for the integration of investigations which have been completed or are underway or in prospect. For example, the vital question of how the occurrence of schistosomiasis among irrigation farmers may be reduced requires an interrelation of studies of disease transmission; of ways in which snail distribution may be affected by canal maintenance, wheat growth, and molluscicides; of the practicability of changing canal design and water distribution schedules; of alternative patterns of settlements and field cultivation practices; and of circumstances in which farmers may be expected to revise crop cultivation, domestic water use, bathing, and other practices.

The application of information on problems known to exist in irrigated projects may be expected to continue as in the past, at a rather slow pace and in piecemeal fashion, unless special measures are taken to speed up the process. The most direct and simple means of getting at the suitability of the planning of new or improved irrigation projects is for the principal agencies engaged in funding such activities to insist upon careful consideration of a few criteria derived from scientific appraisal of the processes involved before going ahead with either new or existing projects. To greater or less degree these criteria are embraced by current review procedures by government agencies. Nevertheless, the prevalence of projects which fall short of taking them fully into account testifies to the timeliness of stressing them now.

The questions which it would be essential to answer for any proposed irrigation venture, in addition to the economic questions of prospective costs and benefits, are: (1) has adequate provision been made for drainage and leaching so as to permanently maintain the quality of soil and water in the root zone; (2) has the full range of alternative measures for achieving efficiency in water use been appraised; (3) has the project study examined the probable effects upon aquatic and adjoining terrestrial ecosystems of changing the hydrological and soil regime in the area; and (4) has the study canvassed and assigned costs to the social and economic measures which would be required to assure that anticipated benefits from crop growth and social stability are realized? Each of these must be addressed to the peculiar conditions of the land area involved.

Where irrigation already is operating, it may not be practicable to await the result of study within a project area before acting to curb deterioration. The project manager may be obliged to take one or more courses of action on a frankly trial basis. It would help assess what is happening to world resources of land and water in irrigation projects if, as a minimum, projects were in future to report periodically on: (1) efficiency of water use; (2) area subject to waterlogging, salinization, and alkalinization; (3) area abandoned because of soil or water quality; and (4) population affected by selected water-borne or vectored diseases. These are simple measures which would yield a rough audit of gains and losses.

In the long term it is to be hoped that institutions responsible for education and training will adjust their programmes so as to anticipate fully these and other environmental issues. Materials made available to them as part of environmental and engineering information networks will assist. In the near future, however, the greatest need is to reach people who have it within their grasp to halt the deterioration and enhance the productivity of existing irrigation and drainage. Unlike some of the changes in forests and grasslands which can be predicted only with wide confidence bands, the deterioration and impacts of arid land irrigation can be projected with moderate precision. Most of the effects are not in dispute. Their remedy lies in applying, with sensitivity to the distinctive attributes of each area studied, the basic models of water, salt, and organic processes that are available.

CHAPTER 4

Environmental Management

This chapter is concerned with human response to environmental issues. As Chapter 2 indicated, such responses generally involve successive action at four levels:

- data capture;
- data analysis;
- presentation of conclusions; and
- formation and implementation of social policies.

In the present chapter the same sequence is followed. The first section describes SCOPE's Mid-term Project VI on problem identification and monitoring. This has sought to evaluate the kinds of information about the environment that can most usefully be gathered. It is far too easy to accumulate vast amounts [illegible] low-quality data that swamp the analytical process.

Monitoring provides an essential input of knowledge about the environment and its trends, on which human responses can be based. Such information needs logical analysis, and it will not easily be interpreted unless there is understanding of how the environmental systems concerned work. Modelling can both guide data collection and ensure that it is analysed in a logical fashion. One use of mathematical modelling techniques, to describe the processes of ecological succession, is outlined in Section E of Chapter 3. Section B of this chapter describes the broad concepts developed in SCOPE's Mid-term Project V on simulation modelling as a whole. As in UNESCO's Man and Biosphere programme, SCOPE has found the discipline of modelling relevant in all sectors of its work.

Through the rational process of gathering and examining precise environmental data and analysing the behaviour of environmental systems, it is (or should be) possible to make valid statements about the extent to which trends in the environment or man's impact upon it create risks. Section D of Chapter 3, describing the Mid-term Project on Environmental Toxicology, covered some of this ground, especially in its annexed case study of the pathways and effects of methyl mercury. A further general analysis of the processes involved appears as Section C of the present chapter.

Studies of ecotoxicology and the monitoring of pollutants alike depend on the feasibility and reliability of analysis for substances present at low concentrations in environmental media and living organisms. This was recognized early in the development of SCOPE's programme and a Working Party under the Chairmanship of Dr. W. Gallay was set up to study the merits and drawbacks of existing methods of analysis for each of the many pollutants involved. The report of this Working Group has now been published as SCOPE 6 – 'Analytical methods for selected pollutants'.

The capture and analysis of data, modelling of environmental processes, and evaluation of risk are unlikely to be useful unless the outcome is effectively communicated to those who make policy decisions on behalf of the community, a fact that scientists are all too liable to overlook. The format for such communication, as Chapter 2 stressed, needs to be different from that used for scientist-to-scientist exchanges. Section B touches on these questions, which are expanded in Section D, where preliminary results of the SCOPE Project VII on this theme are summarized. Finally, the sequence should end in some kind of social response if the risk makes this necessary and the communication has been adequate. SCOPE Project III on Human Settlements examined the building standards that have been adopted in developing countries. This study revealed that the logical processes of analysis, evaluation, and establishment of a response appropriate to the particular circumstances of a community have not always been followed. Some developing countries still employ standards adopted from wealthier countries in other environmental zones, even though these are clearly irrelevant and at times even wasteful!

A. PROBLEM IDENTIFICATION AND MONITORING

1. Introduction

In environmental management, decisions are most often made in a context in which the outcome is in doubt and the consequences of a given choice cannot be fully predicted. Practically all environmental management involves making decisions under conditions of risk or uncertainty. By 'risk' is meant the likelihood or probability that an event, usually considered as adverse, will occur. By 'uncertainty' it is intended to denote the confidence or lack thereof which can be specified for a given estimate of probability.

There are three main sources of uncertainty in dealing with the environment. These are (1) stochastic variability of the processes involved, particularly the occurrence of rare events such as floods, droughts, and earthquakes; (2) inadequate scientific understanding of how the processes work or of the behaviour of the environment; (3) inadequate data or records for the phenomena or the locality under study.

Methods are available for predicting the probabilities of rare events, given historical time series of sufficient length. Engineers use these methods in the design of flood control systems, tall buildings, and so forth. When an event has been specified in probabilistic terms, however, uncertainty remains as to its time of occurrence.

Uncertainty associated with lack of knowledge and data is difficult to reduce by resort to probabilistic techniques. This is compounded by the fact that uncertainty increases as the prediction or forecast extends further into the future.

2. Problem Detection

From the large array of both natural and man-induced environmental changes that continually occur, it is important to identify those that are, or might become undesirable. The process of discovering and identifying environmental risk has not been well studied. There are three systematic processes which may be used. These are screening with testing, monitoring, and diagnosis.

Screening and testing is commonly applied to new situations, for example where a new product or process is to be introduced and systematic observations and tests are conducted to determine in advance the risk of adverse effects.

Monitoring is also a method of risk detection. Widespread and especially regular measures of environmental variables may reveal changes or anomalies which help in the identification of a risk. For example, the monitoring of carbon dioxide in the atmosphere has indicated the possibility of climatic change. In addition, monitoring can aid in estimating the magnitude of a possible risk.

Diagnosis is a method of risk estimation that is applied where adverse effects or symptoms are evident, leading to a search for causes and often to the identification of some hitherto unsuspected or unverified hazard.

Beyond these three systematic processes lies the broad body of basic scientific enquiry. At any time, logical deduction from existing or new knowledge may lead to the identification of environmental risk. Such a process demands a creative leap of imagination in the mind of usually an individual scientist, who makes a connection or sees a link that has not before been made (Koestler 1964). Such inspiration, intuition, or creative imagination will always be needed and cannot be programmed. However, the conditions in which it can occur need to be created and maintained.

3. Monitoring

a. The Present Interest in Monitoring

The concept of a Global Environmental Monitoring System (GEMS), was endorsed by the United Nations Conference on the Human Environment in June 1972. Many publications (United Nations Environment Programme, UNEP/GC/24 1975, SCEP 1970, SCOPE 1971, SCOPE 1973, NAS 1976) have set out the needs of a global system and the variables to be measured. Some of the proposed schemes are ambitious, idealistic, and very comprehensive.

Despite recent activity, there is disappointment in certain quarters that the idea of a comprehensive monitoring system is not being translated into reality. The delay in implementation may be connected with the fact that deficiencies exist in our basic understanding of how to go about monitoring and hence how to build a comprehensive global monitoring system. The initial generalized planning is much easier than its subsequent practical implementation. A notable exception is atmospheric monitoring. Long experience motivated by the practical need for weather forecasting has led to an advanced understanding of monitoring needs.

The fact remains, however, that in spite of the voluminous amount written about 'monitoring' in general, fundamental semantic, scientific, technical, and procedural difficulties, as well as differences of interpretation, exist. Up to the present these difficulties have hardly been recognized, so that 'monitoring' has been taken up perhaps with more enthusiasm than understanding and has become something of a vogue word. A reappraisal of the scientific and technical basis upon which so many of the ideas and activities planned at present tacitly rest is needed. Such a reassessment might help to identify fundamental differences of approach and existing gaps in our knowledge, leading to a wider endorsement of actions needed to be taken next in order to create a practical global monitoring capability.

b. A Definition of Monitoring

Monitoring is defined here as the collection, for a predetermined purpose, of systematic, inter-comparable measurements or observations in a space-time series, of any environmental variables or attributes which provide a synoptic view or a representative sample of the environment (global, regional, national, or local). Such a sample may be used to assess existing and past states, and to predict likely future trends in environmental features.

Monitoring is thus a systematic method of collecting data needed for environmental problem solving. This is its principal justification. It is a matter of scientific and technical skill to be able to carry out appropriate measurements with enough precision on samples drawn from suitable locations over an adequate period of time to get the necessary information for the lowest cost.

Monitoring observations commonly fall into four categories where different types of variables or characteristics are being observed:

(i) measuring *levels* of potentially harmful or beneficial chemical substances in the media of air, fresh water, seas, soils, sediments, living organisms (including man and his food);

(ii) measuring physical *attributes* of the above media such as solar radiation flux, soil chemistry and texture, turbidity of air or waters;

(iii) measuring the frequency and severity of the beneficial or harmful *effects* on living things caused by such chemical substances or physical attributes under (i) or (ii) above, such as population size, disease incidence, biochemical, physiological, genetic, or behavioural variables; and

(iv) taking inventories which (a) reflect the state of the recent climate such as area of ice caps, mass of glaciers, or sea-water level, (b) quantify human impact such as deforestation-rate, crop-area, urban-area, or energy or resource use.

A great deal of monitoring has already been done all over the world, usually in order to answer pressing local or national problems. Although summaries of the results have been published in scientific journals and reports, many of the data are stored in archives around the world. Broadly similar parameters are monitored from country to country, although each nation has its own specific objectives. Thus, although a great deal of the data are capable of being collated to form a crude picture of states and trends in the global environment as a whole, this largely remains unattempted because the data were not originally collected for this purpose, nobody at present really knows how much measuring has been done and where, and there is no general agreement on methods of sampling and measurement (or observation), so that much of the information collected is not inter-comparable in space or time.

Although these defects make it impossible to use all the current data to their fullest extent in a global context, there is still enough comparability of methods and global coverage to make it worthwhile to attempt to review the existing data and to obtain from them a first approximation of the environmental status of several parameters, particularly chemical variables. The International Referral System for Sources of Environmental Information (IRS) is a first step towards determining how much measuring has been done and where. However it is important to remember that IRS has no assessment or review function. The International Registry for Potentially Toxic Chemicals (IRPTC), another UNEP initiative, is also currently being developed and may well possess more of a review function.

Any critical review or appraisal of existing data is bound to sharpen perception of how to embark on future monitoring. Such critical reviews should be carried out in tandem with the planning of future monitoring schemes, always providing that such collation work on existing data does not try to extract more information than the precision of the data will reasonably bear.

c. Criteria of Approach to Monitoring

A good reason should exist for embarking on any monitoring activity, either a wish to investigate the structure and functioning of some part of the environment in order to understand it better, or a need for more information on some specific problem.

A perturbation in one environmental compartment (such as air, freshwater, oceans, and land) usually has repercussions in others. In other words, side-effects habitually appear in places other than where the environment was first perturbed. It is thus essential to have a good working knowledge of environmental transfer processes in order to predict the scale of the effects which may arise in all environmental compartments from a perturbation in any one of them. Biogeochemical monitoring programmes can provide basic information for making such predictions.

Side-effects may well appear remote in time and space from the perturbation which originally generated them, because these environmental transfer processes take time. Thus side-effects which could be unknowingly triggered may be unstoppable and virtually irreversible by the time they first appear or are perceived. Environmental systems may also be resilient to change and show no detectable side-effect despite repeated perturbation. A detectable side-effect may in such cases occur somewhat suddenly or even catastrophically following a critical threshold quantity of a perturbation, applied in one dose or in successive increments, being exceeded (Holling 1974). Both time-lag and resilience phenomena as well as environmental transfer processes have very important implications when choosing the correct approach to monitoring.

The overall cause-effect concept of a man-induced perturbation (dose) increasing to a level where it generates a significantly inconvenient side-effect (response) is tacitly assumed to apply to all environmental disturbances. In consequence, the building up of a knowledge of the environmental dose-response (level-effect) relationship is basic to the proper assessment of monitoring data. Typical examples are: grazing pressure at specific seasons versus sward productivity (carrying capacity); concentration of lead in human blood versus frequency of lead poisoning symptoms; fishing effort versus fish-stock size; frequency of irrigation ditches versus incidence of malarial mosquito larvae; and global atmospheric carbon dioxide concentration versus global atmospheric energy balance and ambient temperature change. Determining the shape of the environmental dose-response curve aids in the determination of unacceptable levels of perturbation (dose). This implies a decision as to what constitutes an unreasonable amount of side-effect or response. This is a very important point because it is often easier, and nearly always more predictive, to measure the 'dose' than the 'response' routinely for control purposes.

The way to build up a detailed knowledge of the qualitative nature and quantitative severity of any side-effects is to study actual situations where the side-effects are occurring. Such situations can often be devised experimentally under controlled laboratory or field-trial conditions. More often, however, our experience has come from accidental perturbations or special cases of environmental disturbances such as from studies of occupational or accidental exposure to chemicals or radiation, or areas of intensive agriculture or other forms of drastic land disturbance. These have provided essential knowledge of various adverse effects which result from a given level of perturbation. Good examples are our understanding of how badly planned grazing regimes contribute to soil erosion, or our ability to monitor for lead poisoning from human health studies carried out in the work environment. Intensively perturbed environments (hot spots) are extremely valuable for calibration purposes in the early stages of developing a monitoring system. However, some perturbations are not geographically confined to distinct areas in this way. Atmospheric mixing imposes virtually no constraints on the possible effects of such atmospheric contaminants as carbon dioxide and chlorofluoromethanes on weather. In such cases it is not possible to find a special 'hot spot' which might give us information as to what the prevailing situation might be globally, if emissions were to go on completely unchecked.

The existence of time-lags in the appearance of side-effects, as mentioned above, is particularly important with environmentally persistent chemicals such as radionuclides or certain toxic metals and pesticides.

The use of models allows monitoring to identify and concentrate on those environmental compartments coming earlier in the environmental transfer sequence for a given pollutant. Apart from additional valuable warning time given, this strategy usually involves a greater economy of sampling and analytical effort when compared with monitoring strategies which concentrate on collecting data on resultant pollutant levels in the eventual target receptor. Ultimately, the monitoring could go right back to the source itself, giving the greatest economy of sampling and analytical effort and the greatest flexibility in devising appropriate management strategies for dealing with that particular single problem. The difficulty, however, lies in the development of adequate models connecting the pollutant levels in different compartments with their consequential levels and effects in the target population. If this can be successfully achieved, however, the results are so informative and generally useful that it would be prudent to use the approach not only for delayed and persistent effects but in all applicable cases where the nature, time of onset, scale, and duration of side-effects arising from an environmental disturbance are poorly understood. In these latter cases this approach helps in the initial characterization of the problem and in defining more precisely the monitoring system required to obtain the necessary information.

d. The Role of Monitoring in Environmental Protection

In addition to understanding the scientific and technical basis upon which monitoring rests, it is also necessary to place in perspective the role of monitoring in environmental protection. The overall process of environmental protection is akin to a complicated problem-solving process in which monitoring plays an integral part.

One way of describing a problem-solving process is to divide it up into a number of 'functional phases'. If these are consistently related to each other in some way, a conceptual model of the whole process can be formed. It is important to keep a balance between the convenience of a simple model and the greater precision of a more complex scheme. Once one starts to identify 'functional phases', it is easy to escalate the procedure to such an extent that a simple method of interrelating the individual phases is lost. Moreover, as more phases are identified, the terminology necessitated expands accordingly and eventually becomes burdensome. On the other hand too simple a model is not informative enough.

An approach which bears in mind these points can be illustrated by reference to Figures 15 and 16. The former shows in matrix form the phases and activities occurring in environmental problem solving, and the latter depicts a model of how the different phases interact both with themselves and with the external environment.

Phases / Activities	Recognition (R)	Monitoring (M)	Assessment (A)	Policy (P)
Identification (i)	Ri	Mi	Ai	Pi
Appraisal (a)	Ra	Ma	Aa	Pa
Response (r)	Rr	Mr	Ar	Pr

Figure 15 Matrix showing the phases and activities occurring in environmental problem-solving

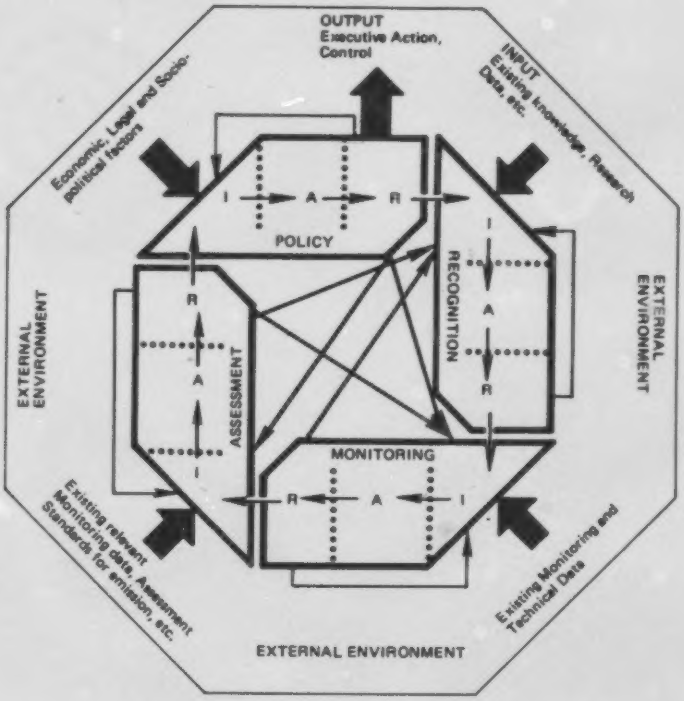
OUTPUT
Executive Action, Control
INPUT
Existing knowledge, Research Data, etc.
Economic, Legal and Socio-political factors
POLICY
I
A
R
RECOGNITION
ASSESSMENT
MONITORING
EXTERNAL ENVIRONMENT
EXTERNAL ENVIRONMENT
Existing relevant Monitoring data, Assessment Standards for emission, etc.
Existing Monitoring and Technical Data
EXTERNAL ENVIRONMENT

Figure 16 Environmental problem-solving model. Note that I = identification, A = appraisal, and R = response

Before proceeding with elaboration of this model, it is useful to consider how the activities of identification, appraisal, and response relate to any one of the functional phases, for example monitoring.

Consider an individual scientist conducting experiments within a programme intended to monitor the levels of either total or methyl mercury in fish. The activity of identification (i) then involves the selection of appropriate methods for the task at hand. The appraisal step (a) in turn involves the measurement of the actual levels of either total or methyl mercury in the species chosen and an evaluation of the scientific significance of the results. Lastly, based on this appraisal, the scientist in question has to formulate and carry out a response (r), whether this be to repeat his experiment in order to collect further data or pass the information to another body for further consideration.

Similarly, persons operating within the other functional phases perform the same three basic activities of indentification, appraisal, and response, though in their cases the scale and context in which these are carried out are different, as are the informational inputs and outputs. Figure 16 outlines this scheme.

Perhaps the first thing to note from Figure 16 is that the whole process is not, as a rule, a simple linear one in which a problem occurring in the external environment is first recognized and then monitored such that information from this phase is passed on to the assessment phase, used, and then fed to the policy phase where appropriate management action is taken.

Consider first the 'recognition' phase. A problem is often recognized in the absence of any formal or institutional mechanisms explicitly initiated to detect problems The lone researcher or the large research team serendipitously stumbling across a hitherto unknown problem is not uncommon. Such a discovery can then in turn lead to the establishment of monitoring programmes designed to uncover the extent or scale of the new problem. However, attempts can be made to formalize problem identification. Two examples spring to mind. The first involves policy decisions to initiate 'think tanks' to discuss different environmental areas with a view to stimulating the identification of possible problems through the process of information sharing. A decision to inaugurate joint conferences between chemists and meteorologists led directly to the shared recognition that halocarbons in the environment posed an environmental problem. This provides an illustration of the feedback loop from the policy phase to the recognition phase, and further refinements in the 'think tank' mechanism can be envisaged as part of the reiterative, quality control loop peculiar to the recognition phase.

The second example occurs when a large monitoring programme set up to monitor a generic group of problems incorporates procedures which can throw light on a previously unsuspected problem. As an illustration, consider a scheme set up to monitor adverse reactions to drugs. Cross-correlations on an ad hoc basis can sometimes provide evidence of causal relationships between certain drugs and specific effects. In this way a feedback occurs from the monitoring to the recognition phase.

Consider now the monitoring phase, from which information on the particular problem is passed on to be assessed. The quality of this information is determined by the intrinsic 'monitoring' feedback loop, which is a quality control loop, one of whose functions is to formulate and modify the monitoring techniques, the characteristics to be measured, and data handling. The validity of the input is checked in this way, and internal consistency and reliability is sought. In effect, this loop acts to improve the monitoring capability so that its output to the assessment phase is suitable for assimilation and action.

The main aim of the assessment phase is to scrutinize and evaluate the input from the monitoring phase and process it in such a way that an assessment of the situation can be transmitted in a suitable form to the policy phase.

It is also necessary to consider the roles of the direct input from the external environment and the feedback loops terminating at the assessment phase. The input from the external environment provides data to be used in conjunction with that from the monitoring phase. This data could be from other monitoring sources or it could be already existing knowledge related to the problem in hand or to similar problems. Likewise, information about existing standards, criteria, or danger levels would be collated and compared with the monitoring phase data.

The intrinsic assessment feedback loop is another quality control loop, in this case one which implies reassessments of the criteria used in evaluating the output from the monitoring phase and demands for more information from the external environment.

The loop feeding back from the assessment to the monitoring phase has two distinct functions. One is as a quality control loop between the two phases. Its second function is as a research tool in understanding the environment.

Finally, at the policy phase, objectives and options are formulated and matched and any resulting plan of action implemented. The inputs to this phase include not only the direct assessment of the basic data transmitted along the monitoring-assessment chain, but also an injection of social, political, economic, and legal determinations and values.

Feedback loops to the other phases act as quality control loops. For example, the loop from the policy to the assessment stage might act to modify any standards previously used in the assessment phase to evaluate the relevance of the output from the monitoring phase. The loop back to the monitoring phase will specifically affect this phase in its role as part of the enforcement and quality control mechanisms, or shift its focus of attention to a modified problem area which may have emerged as a cause of public concern. The existence of these feedback loops ensures that each phase is sensitive to all the inputs.

The preceding Environmental Problem-solving Model can be used to appreciate the role particular monitoring strategies play in environmental protection schemes. The two examples which follow are drawn from the fields of resource management and pollution control respectively.

An important reason why the management of natural resources is a problem of much greater complexity than the management of many pollution problems is that natural resources tend to form interacting components of dynamic ecosystems in which change is an integral part. Long-term changes can occur through trends in climate and in soil structure and chemistry, and through natural successional processes. For example, the occurrence in parts of Africa of tropical rain forests on fossil sand dunes indicates the potential magnitude of this type of change. However, the time scale of these changes makes them of relatively minor importance to present-day management systems. Short-term responses in the environment to high and medium frequency perturbations such as rainfall and temperature can be of considerable importance. Fluctuations in the grain harvests of the USA and USSR and the Sahelian drought illustrate the very real importance of these perturbations. These changes are induced by management practices and especially by land-use control strategies. Sustained high levels of productivity resulting from intensive farming practices, and the creation of sterile, saline soils from badly planned irrigation schemes are both examples of this type of change.

Any environmental management system must be responsive to these types of change if it is not to become out of phase with them and cause possibly disastrous results through positive feedback. In order to achieve this responsiveness, a continuous and iterative monitoring programme must be maintained. In fact, the major role of monitoring in resource management is to provide a constant and efficient feedback of information specifically to maintain flexibility and responsiveness in the policy stage of the management process. In the case of such complex systems, both the assessment and the policy stages in particular must, therefore, be based on some form of working model of the environment. The model must, firstly, include the baseline characteristics of the area, and must take into account the dynamic interrelationships between the various levels of the local environment as well as its inherent variability. It must then be able to predict the response of the environment to a whole range of management options. There is no doubt that a continuously iterative system of monitoring and model building forms one of the most powerful tools in natural resource management.

Working examples of this approach to environmental management and resource utilization are uncommon. However, one example from Africa can be briefly considered, both as an illustration of the environmental management model proposed in Section (d) and as a promising approach to resource management.

In Tanzania, East Africa, the National Parks are faced with the task of managing their conservation areas as renewable natural resources. In the Serengeti National Park, a multidisciplinary team of scientists has designed a management system based upon a long-term, large-scale monitoring programme. Supporting short-term research projects have produced a number of predictive models for different aspects of the Park's ecology and these are utilized with continuous development of a generalized model which predicts the response of the whole ecosystem to alternative management strategies, outside influences, and climatic variations. The monitoring programme is based upon, and feeds information into, this generalized systems model.

This has maintained a dynamic flexibility in the management of the Serengeti. For example, concern was expressed about the possible over-grazing of the pasture following the eruption of two ungulate populations. Five detailed research projects were initiated into the primary production of the grasslands and into the dynamics and movements of the populations concerned. These projects indicated that the populations would stabilize through density-dependent feedback processes before the rangelands became over-grazed, and models were formulated which predicted the population level at which this would occur. On the basis of these findings, the active management of these populations through culling was considered unnecessary. These population models were subsequently absorbed into the monitoring programme, and data were continuously collected in order to check the validity of the models and to ensure that the predictions were proved to be correct. Up to now the populations have behaved as predicted, and active management is still considered unnecessary. However, monitoring will still continue in case the situation changes.

The fact that the emissions of fluoro- and chlorocarbons (e.g., CCl_3F, CCl_2F_2) constitute an environmental problem was suspected only a few years ago. The chronology which follows (Table 3) is intended to illustrate the terminology used in

TABLE 3 Chronology of Recognition and Response to the Problems Posed by Halocarbons

Management Phase		Date	Event
External Environment		Before 1970	Introduction of the use of CCl_3F and CCl_2F_2 and their subsequent release to the atmosphere.
Recognition	(I)[a]	1970	Invention and development of a device capable of detecting CCl_3F in ambient atmosphere at concentrations of about 50 parts per 10^{12}.
Assessment	(A)	1970–1971	Association of CCl_3F transport by atmosphere with emissions from anthropogenic sources
Monitoring	(I)		Use of halocarbons to observe atmospheric motions.
Assessment	(I) (A)	1972	Identification of substance as potential long-range atmospheric tracer.
Recognition	(R)	1972–1973	Improvements in halocarbon detection methodology. Expansion of measurement programmes.
Monitoring	(I)	1972–1973	Detection of increasing atmospheric concentrations of halocarbons.
Assessment	(I)	1973	Identification of photolytical decomposition of substances. Identification of interactions between Cl^- and O_3.
Assessment Monitoring	(R) (I)	1974	Study programmes designed and commenced in order to elaborate stratospheric chemistry including that of halocarbons, water vapour, NO_x, etc.

TABLE 3 *(continued)*

Management Phase		Date	Event
Assessment Recognition	(R) (I)	1974	Further improvements in instrumentation for measurement of CCl_3F concentrations; detection of CCl_2F_2.
Monitoring	(I)	1974	Stratospheric flights to obtain concentration profiles of CCl_3F, CCl_2F_2.
Monitoring	(I)	1974–1975	Development of methods to detect ClO, HCl at minute concentrations (≤ 1 in 10^9).
Assessment	(I)	1975	Data on halocarbon atmospheric concentrations. Models and associated environmental effects assembled.
Assessment	(A)	1975	Organization of comprehensive, interdisciplinary, inter-agency groups to assemble and consider all available relevant information.
Assessment Policy	(A) (A)	1975	Comprehensive reports qualitatively assessing current knowledge and applying economic-physical models to assess future situations. Reports: 'Fluorocarbons and the Environment' – Report of the Federal Task Force on Inadvertent Modification of the Stratosphere; 'Possible Impact of Fluorocarbons and Halocarbons on Ozone' – (May 1975) Interdepartmental Committee for Atmospheric Sciences.
Monitoring	(A)	1975	Increased measurement effort in space and time and equipment development.
External Input to Assessment	(A)	1975	Further theoretical studies of chlorine chemistry and radiative transfer effects. Analysis of increasing CCl_3F, CCl_2F_2.
Recognition	(I) (A)	1975	Detection of additional chlorine compounds in the atmosphere (e.g., CH_3Cl).
Policy	(A) (R)	1975	Recommendations for initiating legislation controlling fluorocarbon emissions.
Policy	(A) (R)	1975 and beyond	Chemical industry studies of alternatives.
Monitoring	(I) (A) (R)	1975 and beyond	Improved and expanded monitoring programmes.
Assessment	(R)	1975 and beyond	Improved evaluations.

[a] The letters (I), (A), (R) are abbreviations respectively for the activities Identification, Appraisal, Response.

the conceptual model above and the interactive and iterative nature of the environmental management process. This section also describes an important example of a process in which the initiation of management actions was based upon models predicting the consequences of specific levels of emission, rather than waiting until such consequences were detected. The models, which included actual monitoring data, indicated that the release of chlorofluorocarbons would have cumulative and persistent effect on atmospheric ozone, causing ozone levels to decrease for decades.

It seems highly likely that similar situations will arise in the future in which 'early warning' will be best provided by an appropriate combination of theoretical models and physical measurements.

This example demonstrates the interactive responses between the four stages of the process model which can act to improve and optimize the information available for management decisions. The recognition, monitoring, and assessment phases were and are often acting simultaneously and constructively to resolve uncertainties. At this time the results are being fed into an ongoing policy phase. The roles played by individuals and institutions led to the establishment of both governmental and private organizations directed to this specific environmental issue.

It is interesting to point out here that this ability to respond arose from an existing, long series of environmental studies into the atmospheric transport of radioactivity, carbon dioxide, and particulates, and into the effects of supersonic aircraft on the stratosphere. Although none of these studies was directly concerned with the halocarbons, a considerable body of professional and administrative expertise could be rapidly mobilized once the new problem was defined.

e. Conclusion

Monitoring of biogeochemical cycles can draw attention to significant alterations in the amount of substances in circulation and appreciable changes in the patterns of the cycles which have been caused by man's activities or by a significant shift in natural events. This gives a yardstick by which to gauge major impacts on the biosphere in relation to both human and natural interferences and helps in predicting whether protective measures, such as changes in release rates of a substance may be necessary. (See Chapter 3B on Biogeochemical Cycles.)

Gradual building up of knowledge about the dose-response relationship from studying 'hot spots' and other cases of special exposure, whether in pollution situations or from other kinds of human impact, helps us to identify levels of exposure which give rise to unacceptable side-effects. Subsequent monitoring schemes can use this knowledge to help decide where perturbations are beginning to approach critical levels and to predict at what rate. (See Chapter 3D on Environmental Toxicology.)

Where side-effects, from the ongoing action of a human perturbation, are delayed, environmentally persistent, or poorly understood, the calculation of the level to which the environment is irrevocably committed helps in predicting limits and hence guidelines for controlling human practices which generate the perturbation. The most prudent course to adopt for global monitoring is the implementation of carefully planned but modest pilot monitoring projects designed to gain experience as well as information about the environment.

B. MODELLING

1. Introduction

For centuries, man has been seeking to understand the environment, and to predict its future behaviour. He has had some outstanding successes in such fields as meteorology, hydrology, and plant physiology. In recent years, he has also developed a modest capability to understand large mixed biogeophysical and socio-economic systems. These scientific methods are all based on conceptual models, however crude, of the behaviour of the universe. Some of the 'laws' of nature are elegant in their simplicity, but environmental systems are often very large, contain random components, and include many interactive couplings. A perturbation introduced at some point in space and time may cause reverberations throughout the entire system. Usually, the reverberations damp out, but there is always the possibility that they may briefly amplify at some other place or time, or that they may even change the state of the system.

The computer provided man with the capability of studying 'big' systems. In 1923, L. F. Richardson could dream of predicting the weather with the help of an army of mathematicians, all solving differential equations on individual desk calculators. This dream became a reality sooner than Richardson might have expected. Today, the phrase 'simulation model' is often synonymous with the phrase 'a numerical representation of a complex system', and the potential applications are enormous, ranging from the behaviour of an individual cell under stress, to models of various world systems.

Simulation modelling of physical, biological, or socio-economic sciences includes a variety of methods, from graphical mapping and empirically fitted algebraic relations representing static or dynamic phenomena, to the use of highly sophisticated high-speed computing (analogue or digital) methods for solving complex systems of nonlinear partial differential equations or stochastic relations representing such phenomena. In order to represent a physical or biological process by equations, in most cases it is necessary to make some simplifying assumptions in describing the process in abstract mathematical language. Such assumptions may be particularly difficult to make if the process in question is not clearly understood and may eliminate from the mathematical equations some essential features of the process. The final results may have serious errors which could be aggravated by the high speed with which the computer may multiply such errors. The power of simulation models lies in the complexity of the systems they can examine; their weakness lies in the simplistic assumptions that are used in some or all of the component parts.

The modeller should realize that his objective is to simulate the behaviour of real physical systems, rather than to communicate more effectively with his computer. On the other hand, the investigator of complex environmental problems should recognize that he may not be familiar enough with the potentialities of simulation modelling developed by the specialists. The difficulties to be encountered in building and validating a big numerical model of a mixed biogeophysical-socio-economic system are immense.

The depth of knowledge of modelling within the ICSU Unions is great, but to a certain extent is compartmentalized. Thus, with the emphasis placed on simulation models at the present time and even more so in the years to come, the need for greater interdisciplinary exchange of knowledge and experience is urgent. In the following sections, the present state-of-the-art is summarized and the likely modelling problems of the next decade are discussed.

2. Purposes of Environmental Modelling

Models of environmental systems have been used for three main purposes: advancement of knowledge, education, and application of knowledge to decision-making.

Simulation modelling can be used in the management of research. In building a model, gaps in knowledge that might otherwise have been ignored can become evident. Where a number of research projects serve a common set of objectives, a model of the system may provide an objective basis for decisions regarding priorities and allocation of resources. The process of sensitivity analysis, which examines the response of variables of interest to changes in different parts of the model, enables research to be concentrated where the benefit is likely to be great.

In schools and universities, models are a way of displaying the chain of cause and effect in a complex environmental system. Building models of systems requires students to recognize the types of interaction involved, and to try to express them unambiguously and quantitatively. Models may also have important educational functions outside the formal educational system. An example is the enormous public impact of modelling work on the global scale by the Club of Rome and others, in drawing attention to the possible consequences of growing population pressures and depletion of resources. Education of the public on the likely future consequences of current trends and activities is a continuing need: the Club of Rome study just referred to also demonstrated that such education must encompass some instruction on the limitations of modelling and the dangers of uncritical acceptance of the results of extrapolation from imperfect data.

For the environmental manager who needs to reach decisions with environmental consequences, as in the case of a terrestrial ecosystem, modelling can constitute a special and sophisticated prediction based on the data at his disposal. These predictions then can be used with his evaluative judgment to arrive at a social policy. A simulation model incorporating existing knowledge of the structure of the system, and of its present state, can be used as a predictive tool. Its utility is influenced by how dependent the system is on unknown future inputs. The predictions may be arrayed as a series of several management strategies. It is as a tool for management and as a contribution to decision-making that simulation modelling of environmental problems plays its most important role.

3. Decision-maker's Outlook

There is no valid stereotype for decision-makers. However, many decision-makers see themselves as operating under a large number of conflicting pressures, and subject to difficult constraints. It is clear that models which will be accepted as useful by decision-makers must take account of political and other constraints, must address those specific problems the individual decision-maker views as important, and must be accessible without requiring an excessive learning period. A final requirement is understandability: a decision-maker may be more likely to accept the conclusions of a straightforward, logical analysis that he understands than those of a complex simulation which he does not. A conclusion supported by many observations is that recommendations arising from simulation studies are most readily accepted by those decision-makers who are closest to operational and technical problems, as with the operator of a water distribution system. This may be due to the fact that these managers are already familiar with such aids as complicated management information systems and optimizing programmes.

The use of models in decision-making is likely to be more effective if decision-makers can themselves be involved in the specification and development of models which they are to use. Otherwise, their values and perspectives cannot be successfully anticipated by modellers. Direct involvement of decision-makers in modelling depends on their willingness to participate as well as on the nature and scope of the problem, and may be impractical at present in many areas or where the highest political and administrative echelons are involved.

4. The Model Builder's Outlook

There appear to be four major issues that an environmental modelling effort directed to decision-making must resolve if it is to be productive:

(a) Model purpose – The development of models for decision-making purposes has been the least successful of the three purposes. Often models have not been designed for policy use or, when they have been, are unsuccessful in fulfilling this objective. Modellers, in general, are primarily scientists, and often seem more concerned with the design and development of models than with implementation. The actual model-building process involves their scientific talents, while the transfer of the model from the research arena to the operational arena may involve quite different skills.

(b) System definition – In forming a framework for analysis, the usual strategy is to divide the problem progressively into subsystems and components, until each component is recognized by the model builder as a segment for which there is adequate understanding. The primary issue may not be addressed, since 'adequate understanding' is never achieved. Another difficulty is failure to define the state of knowledge for each component of the system. Lacking this definition, a commitment is often made to a level of resolution where information on many components is inadequate and models based on existing experimental data are more likely to be completed than models that require new data from experimental observations.

(c) Interdisciplinary integration – Interaction between modellers in different disciplines, in practice, is difficult. Given a sector of a model to construct, individual scientists often prefer to explore the frontiers of this topic in more and more detail rather than develop simple representation adequate to support the total model. In addition, those components of the model that are strongly supported by theory and data are emphasized while those areas weak in theory tend to be underdeveloped. This, combined with the difficulty of establishing interdisciplinary linkages, may result in models that do not successfully address the whole system.

(d) Documentation and transfer – Understanding of an existing model requires knowledge of the nomenclature and philosophy of the disciplines involved as well as of the modelling language. Model documentation is difficult, and, even with minimum acceptable documentation, many features of a model remain in the mind of the modeller. When the modeller leaves, the model also leaves. Most model builders have little interest in model use. Models that process data or focus on resource allocation problems are currently easier to transfer into the policy arena than are actual simulation models because they perform functions similar to those already in use. Models that require practising analysts to develop new skills will not, on the other hand, be as readily accepted. The insight obtained through model construction may be easier to transfer to a key group of personnel than an entire, fully developed model itself. The concept of constructing basic modules that can be combined into many models has been advocated, but seldom successfully developed.

5. The Gaps

Major gaps exist in those common areas where the facets of environmental modelling interact.

A central theme running through many of the interface issues is one of communication, between human beings, between disciplines, between computers, and within disciplines. If the decision-maker and modeller fail to understand the common problem, whether it be one of predicting the consequences of a decision on control of a contaminant or finding an optimum solution to a resource allocation situation, no progress may be made, and future interactions may be harmed. Even if both sides understand the common problem and a solution is produced, there may still be difficulties because the decision-maker may feel that his power is being threatened by the results of the model.

The decision-maker and the modeller are often heavily constrained by working within limits of time, money, knowledge, personnel, and equipment. The restrictions that limited resources bring to the effectiveness of environmental modelling, particularly in the developing countries, should be specifically defined at the beginning of any work.

It is only recently that some effort has been made to study the transferability of models. Compatibility between programming languages, between computer systems, and between documentation is a major concern. Another question is whether the problem being addressed has already been solved and, if it has, if the solution can be used in the local or particular situation under study.

Another concern is interfacing between different types of models, although separate disciplines tend to favour a limited range of models within their own domains. The scale (both temporal and spatial) of aggregation, and of precision, can often be very different when studying separate submodels of the environment. Some difficult decisions have to be made when trying to incorporate these factors into a main environmental model. The decisions should be made explicit and their effects assessed by the environmental manager.

6. Environmental Simulation Models

It has already been observed that most modellers restrict themselves to only one or a few of the many logical, structural, and philosophical approaches to the subject of simulation, and that this sometimes results in a communication problem within the modelling community itself. This can be counteracted by a classification or taxonomic scheme, which need not be particularly detailed and need not involve careful definitions of terms, but can rather be constructed using only a few key descriptors. Suggested below is a fivefold classification, including:

(a) Purpose: Is the primary purpose of the model to provide (i) information for policy decisions of some duration, (ii) assistance in day-by-day operations, (iii) educational or training purposes, or (iv) information used to gain understanding of the system itself?

(b) Distance Scale: Is the area encompassed by the model best described as (i) local, (ii) regional, (iii) national, or (iv) global?

(c) Time Scale: Does a simulation run provide information on the scale of (i) day-to-day operations, (ii) periods up to one year, (iii) from one to several years, (iv) more than ten years, or (v) is it a static model providing steady-state information only?

(d) Type of System Modelled: From a list of descriptors provided, the most appropriate words or phrases should be chosen to describe the system being modelled. Examples would be: regional air pollution, coastal fisheries management, heavy metals transport in rivers.

(e) Model Type: Descriptors should be chosen from a list such as: stochastic, deterministic, linear-programming, dynamic, normative, descriptive.

In addition, note should be made of any constraints impeding further development or successful implementation of the model such as data shortage, user credibility, or validation expense.

Many examples of modelling studies could be given within such a classification. Two instances are the applications of population-dynamics models such as those of the spruce budworm (Holling 1974) or certain commercial fish populations. These can be thought of as quite successful applications, concerning which it is worthwhile to make three observations: first, that decision-makers were involved in the studies from the outset; second, that the decision-makers involved had technical backgrounds; and third, that an extensive and reliable data base was immediately available.

Another promising application involves numerical studies of atmospheric phenomena spanning short-range pollution studies and global-scale weather forecasting. These studies are generally very complex but the results are easily accessible to non-specialists and have been under discussion for many years. Both of these points have contributed strongly to the credibility of the models.

At the larger end of the modelling spectrum the early presentations of world socio-economic models experienced considerable criticism, and may be described as strongly aggregated models, the technical details of which were not readily available. Furthermore, many subtleties and special interests were not adequately represented in these models. More recent studies have specifically addressed several of these points and have been rewarded with greater credibility. In general, however, models with a considerable socio-economic content are less likely to be accepted by decision-makers than those based on purely physical-biological systems, partly because of the less secure data base, but also because of the difficulty of defining values inherent in social policy judgment.

At the intermediate level are studies such as detailed watershed or catchment models. These studies deal with aquatic, hydrological, and atmospheric transport, are of intermediate size, and involve detailed input from decision-makers. From the standpoint of technical suitability and of credibility, these are successful environmental management simulations.

7. The Potential for Environmental Systems Analysis and Model Building

Unfortunately, many of the models of the past decade have fallen far short of expectations. Those typically accepted or understood by decision-makers and the public belong to the monodisciplinary or technical-operational level, such as diffusion models in pollution control and pest management models. Models of an intrinsically complex and interdisciplinary structure have usually not been applied beyond either academic interests or normative perspectives. This situation is not due to lack of potential in systems analysis and model building. Rather, the understandable excitement of at last being able to grapple with complex problems led to grandiose dreams. Nevertheless, useful and usable techniques have emerged from small groups of scientists, who have had an interdisciplinary background and have made great efforts to link the modelling effort with policy questions and vigorous data validation from the start. Disregarding the early 'over-selling' of the simulation modelling technique, some useful progress has been made.

With the aim of improving the potential of environmental systems analysis and model building, the following factors need to be taken into consideration:

(a) Training of the modelling project co-ordinator in interdisciplinary approaches. It appears to be more effective to organize an interdisciplinary team in which individual members include exposure to, at a minimum, the necessary backgrounds of systems analysis, ecology, geophysics, social science (economics at least), and behavioural science. This exposure need not necessarily be deep, but should be balanced over the required areas. Special training centres should be prepared to fulfil this need, in and for the Third World. Venezuela and Japan are currently being prepared to house such centres.

(b) Creating clearing houses for data and models. It may be helpful to new modelling activities if special arrangements are made to provide ready access to relevant knowledge and experience. This might, for instance, take the form of a clearing house for each continent where a data bank of environmental information is maintained, and existing models are stored. Computer networks for ready transfer of this information would also help.

(c) Using semi-quantitative or purely qualitative methods. This approach should be cheaper in terms of data and resource requirements than most current rigorous answers to the basic questions posed. It may also be expected to help developing countries and further public education.

(d) Rendering modelling methods compatible with incremental decision-making. Basically, there are two different types of models for decision-making: technocratic and incremental. In the technocratic approach, one starts from the recognition and analysis of the problem, and then, through review of all feasible alternatives, the optimal solution is eventually chosen. The second, or incremental approach, is rather common and assumes that there is no decision or solution on a long-term basis, but a continuous stream of minor decisions on a subject whenever this subject confronts the decision-maker.

8. Bridging the Gaps

a. Scientist to Decision-maker

Decision-makers will rely on management procedures, as long as they are successful. Even when success deserts them, they will attribute this to circumstances, unless something or someone makes them feel that new insights are necessary and that the policy itself requires innovation. The steps and rules for building credibility of the environmental scientist, systems analyst, and simulation modeller are:

(i) to make the decision-maker aware of the problem, for instance, by furnishing objective analyses of critical and/or dangerous events;

(ii) to be constructive in criticism of past policy, to say how things can be improved without neglecting the constraints that the decision-maker must observe (political acceptance, etc.);

(iii) to point out that indeed the assessment of environmental impact cannot yet be based on an integrated science of ecology, technology, economy, and sociology, but that the relative evaluation of alternative measures is now possible;

(iv) to help make the decision-maker's task easier by participating in public educational activities remembering that politicians have to be elected and that the scientist also needs the support of an enlightened public;

(v) to make environmental sciences and the application of systems analysis and simulation modelling more acceptable to the scientific community by basing it, to the degree possible, on solid scientific work, and giving other disciplines the credit they deserve; and

(vi) to listen to the problems as seen by the decision-maker and take the initiative in devising effective channels of communication (SCOPE 1975a).

Environmental impact analysis often requires a long-term and global or universal approach, but decisions have to be made locally and cannot always be delayed. Thus, the simulation modelling of some environmental management problems on the world scale may be very logical from the scientific viewpoint, but be entirely unrealistic from the political viewpoint. Policy suggestions made by simulation modellers must face this dilemma. A few initial successes will improve the chances of decision-maker and systems analyst becoming a team whereas initial failures will impede progress for years; therefore, generation of unduly high expectations by the politicians and the public must be avoided. The costs of developing a satisfactorily validated model are often grossly underestimated. In communicating with the decision-maker it is a part of the responsibility of the scientist to make sure that these costs and the prospective benefits are taken into account in initiating the modelling effort.

b. Scientist to Scientist

To environmental scientists it is clear that a truly problem-oriented approach is required and that this will in turn require co-operation among the disciplines.

Development of simulation models that span the disciplines might prove to be effective in tackling complex problems that a single discipline cannot master, as well as in bringing scientists from different disciplines together.

It is widely appreciated how difficult it is to become a specialist in each discipline; however, because there is little appreciation of the necessity to look at problems that require co-operation, those scientists who point out the holistic nature of the human predicament are often regarded as would-be generalists who know 'nothing about everything'. This is in part a dilemma which can be overcome by teamwork. It is possible that universalists of the past will be replaced by teams of experts whose knowledge and experience will be accumulated and integrated through simulation, gaming, and other techniques for improving communication between groups.

c. Gaming

Gaming provides an extension of simulation modelling by allowing the user of simulation techniques to introduce the decision-maker's behaviour into the simulation process. Decisions are made between the time steps as the simulation proceeds. The user becomes more aware of the complex of factors that should be observed before allocation of resources. He performs these allocations and then lets the in-built dynamics of the underlying simulation model carry him to the next time step. The adjustments and compromises with other users who simultaneously represent other interests allow him to see political, social, economic, technological, ecological, and psychological constraints that might otherwise escape attention.

d. Handling Uncertainty

Simulation models are always subject to uncertainty; in their structure, in the data incorporated, and in any future inputs that are assumed. The only hope for successfully dealing with these combined uncertainties, given a certain level and structure of knowledge, is to make these sources as explicit as possible, and to distinguish clearly established facts and relationships from assumed or less established data and relationships. As research continues, knowledge increases, the simulation (or gaming) process is organized in such a way that newly acquired relevant knowledge can be absorbed in a continuous updating process. Only a highly flexible and modular simulation technique can achieve this end. Remaining uncertainty can be dealt with by analysing the effects of varying assumptions; this is essentially a sensitivity analysis. Identification of areas which urgently need further research can emerge from these studies. Also, decision-makers learn more about the sensitivity of the system to the set of alternative policies or measures they are considering.

e. Validation and Credibility

A simulation model cannot be validated solely by reproducing past phenomena and past time series, particularly if it is to be used for assessing present or future alternative policies. Perhaps the gravest validation problem the modeller faces comes from structural change in the real system. Often, the parameters of a simulation model with fixed structure are fitted to generate past time series for a period of time in which the structure of the real system has changed, and the same model is then used to simulate a future in which the structure might change again. The only chance to develop models which can be structurally validated is to leave those parts of the model structure variable which do not represent invariant relationships during the time period under analysis. Clearly, even dynamic models are not adequate unless structural variation is introduced. Because opinions differ widely on which structures can be affected and which cannot, only such models as allow the user to vary structural assumptions may be acceptable to decision-makers who expect or want structural change. Again, the extension of simulation modelling by gaming seems to offer procedures for generating the credibility required.

9. Steps toward Improvement

Environmental models cannot usually be tested in a laboratory under controlled conditions. However, simulation models often provide some clues concerning the causes and the effects, and a sensitivity analysis may suggest experiments in areas of science where fundamental research might be most productive. The use of both mathematical and physical models to represent a complex environmental situation will, in many cases, be effective particularly if the method of using some simple laboratory models is first compared with a mathematical simulation of such models and a direct verification is made of the conditions under which such a use is justified. Based on such a validation the more complex environmental situation could be modelled with a greater degree of confidence. A further validation will, of course, be necessary by comparing the simulation results with the real environmental conditions.

In order that the full contribution of simulation modelling be realized, it will be necessary to address several main groups of problems.

(a) The sophistication of modelling in those fields where it has been less developed should be pressed forward in co-operation with such bodies as the International Institute for Applied Systems Analysis (IIASA).

(b) Every effort should be made to disseminate knowledge and interest in modelling among practitioners in these fields.

(c) All those concerned with modelling as a tool in environmental management should recognize the desirability of involving the decision-maker in the model-building process from the earliest possible stage.

(d) Special attention should be given to the difficulties of interfacing models from different disciplines and at different scales of space and time. In particular, this will be the case with physical, biological, and socio-economical models, when some inputs are measurable while others are in terms of value judgments.

(e) A major effort should be made to call the attention of those ICSU Unions and Scientific Committees whose expertise is within the physical, mathematical, and biological sciences, to the need for basic or applied research on those scientific problems which are not fully understood and which presently require, for their simulation, the use of empirical relations, unjustified assumptions, or guesses.

(f) Co-operative studies with the Committee on Space Research (COSPAR) on the possible application of simulation modelling in the study of atmospheric pollution and interfacing of data derived from satellite observations with those obtained near the ground or sea should be planned.

(g) Co-operative studies with the Scientific Committee on Oceanic Research (SCOR) on those problems of simulation modelling of oceanographic processes which are of common interest are desirable.

(h) Existing techniques for optimization of space and time distribution of monitoring stations should be examined on an interdisciplinary basis. Each discipline has solved or ignored this problem in its own particular way, but no attempt has yet been made to synthesize across disciplines or environmental media.

C. RISK ESTIMATION

1. Concepts

The word 'risk' can be used in two senses. In everyday speech it can imply a value judgment about the severity of consequences of a possible event. Under such circumstances the appreciation of risk can be very different from community to community according to the base line from which it is judged. In scientific terms, however, the word is used more strictly to denote the probability of an event and its estimated consequences, usually an event whose consequences have been identified by a value judgment system as being 'undesirable.' In this section of the report the word is used in the latter context.

When a risk has been identified and when models of environmental processes suggest adverse effects, there is need to specify the degree of risk in precise terms. Increasingly, scientists are called upon to calculate estimates of the risk of certain conceivable events occurring and to state the consequences in probabilistic terms if such events were to occur.

Decisions always involve risk estimates, and the methods of estimation have been steadily improved. It is now possible to state with considerable accuracy for some countries the general risk of death or severe injury for private car drivers or passengers, for passengers on commercial aircraft, or from crossing the road. These technological risks are somewhat easier to estimate than environmental risks where the connection between an event and a consequence is often not so direct or immediate.

Where scientific estimates are not available, and in some cases where they are, reliance is placed by some on acts of revelation, especially as performed by individuals claiming superior authority or ability in such matters. While scientifically doubted or discredited, such methods are still widely in use and widely believed. Many environmental management decisions involve assumptions as to what risk estimates people will make for themselves or accept upon authority, however dubious.

One method of revelation is the practice called water dowsing, water divining, or water witching. Many farmers call in a water dowser who with the use of a forked stick, preferably hazel in many places, claims to detect or reveal the best place in which to locate a well. While this process is scientifically doubted, and no process or causal mechanism can be described in scientific terms, it is widely used.

Another non-scientific method of risk estimation that is widely used is intuition. Laymen, as well as scientists, use intuition in their daily lives to reach decisions and make choices. Intuition can be defined as 'reaching a conclusion on the basis of less explicit information than is ordinarily required'.

When the choices to be made are numerous and trivial (i.e., the consequences of a wrong choice are not serious) intuition may be a satisfactory way to proceed. It saves time and effort in making more scientific estimates. Where major consequences are at stake, intuition alone is not recommended.

There are three main scientific approaches to risk estimation: extrapolation, reverse extrapolation, and analogue methods.

The most systematically employed methods of estimation involve the use of extrapolation from experience. Most common is the projecting of past events into the future in order to estimate likelihood of events or rates of continuance of observed trends. Estimates of changes in atmospheric composition serve as an example.

Reverse extrapolation is a method of tracing backwards from imagined events and consequences, reducing the risks to a series of component events for which experience does exist. Such methodology underlies fault tree analysis of the risk of failure of complex engineering structures. Core meltdown and subsequent release of fission products, for example, is a conceivable event at a nuclear generating station. Such an event has never occurred, but the structures and processes of the generating station can be reduced to component links for which there are experienced rates of failure. Risk estimates in this case involve a series of contingent probabilities.

A third approach to extrapolation is the analogue method in which experience is transferred from a different but not dissimilar situation. For example, estimates of the maximum probable flood in a small river basin with poor records may be achieved by transferring known weather patterns of the region into that basin.

2. Example of Risk Estimates

There is an extensive literature on the risks of late effects from the irradiation of the human body and its organs and tissues with ionizing radiations. There are many recommendations, in effect or being proposed, for dose limits for ionizing radiations. Thus the risks for any dose limit can be estimated and compared with other risks of ordinary life for populations or with other risks in industry for occupational workers.

A recently proposed standard for the protection of populations is an annual dose equivalent to the whole body of 25 millirems (US EPA 1975) for the whole fuel cycle. The risks of late effects from this dose rate are (Rothschild 1973):

(a) Fatal cancers, 3 to 13 cases per year per million people (C/Y/M) irradiated. The total cancers would be about twice this number (NAS 1972). These numbers may be compared with the rate of cancer deaths per year in the USA, 1,700 C/Y/M. Thus 25 mrem per year would given an increase of about one-third of 1 percent.

(b) Genetic injury to the first generation, 5 to 80 C/Y/M. The higher rate established at equilibrium, after the irradiation of several generations, would be about ten times higher (NAS 1972). This may be compared with a natural incidence rate of 60,000 C/Y/M. Again 25 mrem per year gives an increase of about one-third of 1 percent.

These rates of incidence may be compared with other risks of ordinary life estimated as follows (Pochin 1974, 1975):

Event or practice	Estimated resulting death rate C/Y/M
Traffic and transport accidents	150
Accidents in the home	130
Smoking 20 cigarettes per day	5,000
Drinking 1 bottle wine per day	750
Pregnancy	230
Oral contraceptives	35
Abortion at less than 12 weeks	20
longer than 14 weeks	170

In addition to these methods of risk assessment, attempts have been made to develop systematic approaches that combine the intuitive judgments of experienced persons with quantitative estimates of probability and trends. These include scenario methods and the technique to analyse judgment. Judiciously used, these might play a role in the process of risk assessment especially where broad concepts of future development are concerned. They are less likely to be useful in the assessment of specific risks.

3. The Future of Risk Estimation

The state of the art of risk assessment was reviewed by a SCOPE Working Group (see Appendix C) (SCOPE 8 1976). Various suggestions are made for improving risk assessment. These include the development of hazard taxonomy, and the examination in a systematic fashion of the role of three types of social risk assessment: (1) in the market-place by buyers and sellers; (2) in the sounding of social concerns, including public polls, surveys, and exercises in public participation; and (3) in adversary or judicial situations.

On the estimation of health risks it seems clear that much might be gained by an application of the thinking developed in the assessment of ionizing radiation and radioactive materials to other forms of environmental contamination. The concepts of dose commitment and harm commitment, reference man, and the linear non-threshold dose-effect relation as developed in the International Commission on Radiological Protection (ICRP 1965) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1972) merit wider application. Section D of Chapter 3, on Pollutants in the Environment, and its annex on methyl mercury, illustrate how this may be done.

Epidemiological studies are critical. For a number of reasons estimates may vary by one or two orders of magnitude. This wide range of estimates of hazard to human health is one of the chief causes of confusion in the public mind and of debate with government administration in setting standards.

D. EVALUATION AND COMMUNICATION

Risk evaluation is the conversion of estimates of risks into social meaning. The meanings may be expressed in symbolic terms, in value (economic and otherwise) and in effect (feelings). There are many dimensions to risk evaluation, and it is a process in which all engage. To bring order out of this diversity it is helpful to think of three approaches to risk evaluation: aversive, balanced, and benefit-risk.

Aversive approaches to risk evaluation are those which seek total avoidance or minimization with little or no attention to other considerations. Examples of aversive risk are the food and other taboos deeply embedded in traditional cultures, some of the standards and regulations set in modern society, and the avoidance behaviour of people everywhere. Risk aversion seeks to achieve zero probability of damage.

By contrast the notion of balanced risk recognizes the continuance of some risks greater than zero tolerance, and seeks to achieve a measure of balance among them by making comparisons. It is well known that people accept much higher risks in some directions than in others although the reasons for this are imperfectly understood. Comparisons may be made in terms of risk of death in standard units of exposure or in other terms. Systematic comparisons of many environmental risks are largely lacking. Such attempts as have been made (Starr 1969) show a difference between voluntary and involuntary risk-taking or exposure and between public and private sector risk levels. A comprehensive examination of environmental risks, if undertaken, would be able to point to areas of relatively high but neglected risk and to risks of much lower probability which receive much more attention.

Related to comparative risk are the techniques of cost-effectiveness analysis. An evaluation of costs allocated to preventing injury and death in three British industries (agriculture, steel handling, and pharmaceuticals) shows wide divergences and an implied differential evaluation of a life varying from thousands to millions of pounds (Table 4) (Sinclair et al. 1972).

It seems safe to assume, given the present state-of-the-art, that were similar analyses to be made of a broad set of environmental risks similarly wide discrepancies would be found in the amounts expended to achieve a degree of protection.

Attempts to compare risks not only with other risks but also with associated benefits are developed theoretically, but deficient in practice. Benefit-risk analysis is a newly developing form of benefit-cost analysis in which the focus is upon a comparison of risks with associated benefits. The assumption here is that higher risks are acceptable where associated or anticipated benefits are higher. The most comprehensive attempt to make such comparisons in the technology assessment field is that by Starr (Starr 1969). No attempts have so far been made to develop similar relationships for specifically environmental risks. It would be worthwhile to try to do so, not because the end result would be convincing (there are many caveats to be entered about Starr's analysis) but because the process of attempting to compare benefits with environmental risks would itself be highly illuminating.

TABLE 4 Comparative Risks, Outlays, and Implicit Life Valuations

	Annual Risk per 1,000 Workers of:				
Sector	Injury	Serious Injury	Death	Average Outlay (£/Worker)	Valuation (£), Death
Agriculture	25.7[a]	4.44[a]	0.197[a]	3 (1966–68)	15,000
Steel handling	72.7[b] 62.54[c]	9.92[c]	0.216[b]	50 (1969)	230,000
Pharmaceuticals	25.0[b] 36.80[d]	2.42[d]	0.020[b]	210 (1968)	10,500,000

SOURCE: Sinclair et al. (1972), p. 50.

[a] Ministry of Agriculture, Fisheries and Food, 1966–68 average.

[b] Annual Report of the Chief Inspector of Factories, 1969.

[c] Department of Health and Social Security Digest of Statistics Analysing Certificates of Incapacity, 1967.

[d] Annual Report of the Chief Inspector of Factories, 1967, and Department of Health and Social Security Digest, 1967.

TABLE 5 A Structure for Risk Assessment

	Identification	Estimation	Evaluation
Methods	Screening and testing	Revelation	Aversive
	Basic research	Intuition	Balanced
	Monitoring	Monitoring	Benefit-risk
	Diagnosis	Extrapolation	–
	Creative imagination	Analogue and transfer	Delphi
		Modelling and simulation	Scenario
			Reverse scenario
Theory	Scientific method	Statistical inference	
		Theory of return periods	

The attempts at synthesis of methods and techniques from many fields into a framework for risk assessment are continuing. A preliminary structure is shown in Table 5. They give promise, if pursued, of being able to reduce the number of occasions in which opportunities are foregone because of excessive or unnecessary fears, the number of hazards that remain unidentified, and the risks recognized but underassessed. The importance of the task is not yet matched by performance, however.

Three themes requiring further detailed research and development that have emerged from SCOPE workshop discussions are: (1) the development of typologies of hazards, events, and consequences; (2) the refinement of methods of risk estimation and evaluation; and (3) the communication and use of risk assessments (Burton et al. 1977, Whyte 1976).

It would also be useful if a series of detailed studies could be carried out of human experience in dealing with environmental risks in order to provide a comparative assessment between risks, among countries, and among methods of identification, estimation, evaluation, and communication (White 1974). National and cross-sectional studies would be required with appropriate guidance from international groups of experts and 'users'. In addition to the insights gained by such an exercise, it would be possible to produce a guidebook or handbook of risk assessment methods and approaches which would be widely used.

The complexity of the research processes involved in risk assessment – identification, estimation, and evaluation – partly accounts for the difficulties that have been experienced in communicating the information content of research results to policy-makers and the general public. There is a widespread feeling in the community of environmental scientists that the manner and process of communication is crucial to the nature of societal response. This is paralleled by a sense of powerlessness to affect the process consistently in desired directions. Behind this feeling lies a lack of understanding of the ways in which scientific communications are used and their effects on public and policy-makers.

It is now only possible to describe some of the symptoms of the underlying difficulty and to outline the main dimensions or variables in question.

In the typology of environmental issues described in Chapters 1 and 2 it was noted that issues frequently are allocated to the wrong category, contrary to the intentions or judgments of the informed scientific specialists. Scientific papers or reports often point to the possible existence of an environmental issue deserving more research and some precautionary actions. There are many such papers and many of them do have the desired effect. That is to say, those responsible do facilitate continuance or redirection of the research and take precautionary or preventive action where appropriate. The process goes on quietly, the responsible policy-maker taking calculated action without major publicity. Often, however, the scientific warning is ignored or passed over. This may be because it fails to come to the attention of the appropriate person or group. It may be because the recipient of the report considers the questions raised embarrassing or awkward to deal with and prefers to let the matter rest. Another possibility is that the judgment of scientist and policy-maker differ as to the significance of the issue.

When this happens an individual scientist or a scientific group may feel a responsibility to inform the public of the suspected danger. This may be difficult to do. The channels of communication to carry the message to the public may not be open or if open the message may strike no response. On the other hand, the message may be modified or exaggerated in transmission and a great deal of public concern or alarm may be generated.

When the spotlight of public interest focuses upon an environmental issue the actions of policy-makers are changed. The policy options may be enlarged in one direction and curtailed in others. The scientific evidence carries less weight and is mingled with the emotional reactions of the public, especially those exposed or likely to be affected. What was a suspected issue may be swept by the power of partially formed public opinion into the category of the real and the urgent, irrespective of reality.

Steps towards the improvement of the processes of scientific communication lie in several directions. It would be helpful to have a more considered and deliberate approach to communication by scientists. For environmental scientists, it is important to be able to communicate accurately and precisely, in terms that can be understood by laymen and policy-makers without distortion of the essence of the message. Such aims are unlikely to be achieved without better understanding than now exists of the factors that affect the 'communicability' of a message and response to it.

Some of the variables that now seem of key importance are the nature of the source of information, the form of the message, and the situation of the recipient.

The communication and response process is affected strongly by its point of initiation. In particular the authority or perceived authority of both the originator and transmitter are important. Usually scientists enjoy a high reputation in the eyes of both policy-makers and the general public. Their pronouncements are likely to be taken seriously and accorded weight. To what extent this authority is eroded by the considerable public disagreement among scientists which often emerges on environmental issues is not known. Two observations from recent studies merit consideration in this context. Scientists remain in the public view among the most reliable and responsible sources of information. Scientists are commonly rated more highly in this regard than members of legislative bodies, government officials, and the men and women of the media.

At the same time surveys show that many people feel that they have insufficient access to authoritative scientific information or to the scientists themselves. It seems important that the authority of scientific statements be protected and enhanced and this requires careful attention by scientists to the statements they make and may benefit from use of specialists in communication. Continuing efforts are needed to carry such statements to a wider audience. The public has never been so receptive to scientific information as it is now, and has never been so hungry for accuracy and authority in such information.

The requirements of authority and accuracy have hitherto been best satisfied by the use of established scientific grounds rather than the mass media. The latter have an unenviable reputation for distortion and exaggeration. The way to improvement lies open, however, and scientists using the mass media to inform the public are in a position to exert much more influence than has been customary.

Scientists could be helped in this regard if more was known about the effect of message content, presentation, and timing upon response. It is not sufficiently understood how message format, its urgency, the magnitude of possible consequences, or the nature of the group exposed affects the character of societal response. More detailed and systematic examination of the record with a variety of formats in different countries and for different environmental risks would prove instructive and the understandings thereby gained would provide an opportunity for the process of communication of scientific information to improve.

Response to scientific information clearly varies greatly with the situation of the recipient. Under present practice such information frequently reaches recipients who are in no position to act or to protect themselves from possible environmental threats. Hence the information may generate anxiety without providing any means for its alleviation. There is research to show that extremely dramatic and threatening information is less effective in encouraging response that when more soberly and cautiously expressed. Extremely scary stories tend to evoke in the recipient a psychological response of denial or impotence to act.

Thus both the target audience of the message and its mode of expression can powerfully affect the likelihood and character of response. The whole process of scientific information and communication in the context of decision-making and government policy, and in relation to public awareness and behaviour, needs systematic study.

E. STANDARD SETTING

1. Introduction

Standards are theoretically promulgated by governments or other regulatory bodies in order to protect or enhance the public health, well-being, and quality of life. Environmental standards are commonly of two sorts, prescribing:

(a) maximum permissible levels of environmental contaminants, or

(b) minimum permissible quality of construction, such as for human habitation or dams.

Ideally these standards are based on scientific criteria which have been defined as a collection of data giving quantitative relations between the cause of an undesirable effect and the probability of occurrence of that effect. In practice these data are considered by the standard setters and taken into consideration with economic and social factors. Levels are chosen which correspond to an acceptable degree of risk for a given situation. As new scientific evidence becomes available, and as social and economic conditions change, standards should be subject to periodic review and amendment.

The procedure for arriving at a standard of type (a) above is illustrated in the summary of the ecotoxicology of methyl mercury (Appendix D). This shows that the most important route of intake of methyl mercury for man is eating fish taken from waters contaminated by mercury compounds. The calculations presented show how the body content of methyl mercury in a fish eaten could be calculated from the daily intake. An example of a body content giving an acceptably low risk of neurological symptoms was also given. In this way maximum permissible levels of methyl mercury in fish could be calculated. To set a standard for a given population would require a knowledge of the amount of fish eaten per day or week and the length of the period of consumption.

The acceptable level in a receptor such as man was defined at the Stockholm conference as a primary standard. The corresponding level in an intermediary stage on the pathway, such as the fish, was defined as a secondary standard. Other secondary standards would be the corresponding concentration of methyl mercury in the water where the fish lived. This is called an Environmental Quality Standard. With adequate knowledge of the quantitative transport from the point of release into the body of water to the final human receptor, acceptable release rates and total releases can be calculated; these are called emission standards.

The other kind of standard [type (b) above] is best exemplified from the field of building and construction. It is illustrated by the work of SCOPE Mid-term Project III on Environmental Aspects of Human Settlements, a summary of which follows.

2. Standards and Criteria for Human Habitations

a. Background

The United Nations Conference on the Human Environment held in Stockholm in 1972 gave prominence to the problems of planning and managing human settlements for environmental quality. The rapid rate of population increase and especially of unplanned urban growth in some developing countries, and the need to improve living standards in at least portions of almost all countries adds importance to these issues.

A primary need in this field is an interdisciplinary appraisal of the existing state of knowledge. One topic regarded as of the highest priority is the evaluation of the scientific rationale behind standards and criteria that influence the relation between the provision of human shelter and the environment, especially in the developing regions of Latin America, Asia, and Africa. Such an evaluation compels a review of current construction methods and density of building with special emphasis on the use of renewable and non-renewable resources, climate, cultural values, building and administration costs, water supply, air quality, occupational noise levels, geophysical hazards, and sanitary and education services. This should lead to a fresh appraisal of what are, for instance, minimum standards for housing density or water supply and should considerably enhance the overall understanding of the essential human needs in a wide range of settlements.

The following objectives were adopted by the SCOPE Mid-term Programme:

(1) to collate existing information on the various standards and criteria that define the environmental context of human settlement and, in particular, determine the supply of housing and other services and amenities;

(2) to carry out an interdisciplinary evaluation of the scientific rationale behind these standards and criteria;

(3) to develop proposals for planning and promoting comparative research into the development of new standards and criteria which may ameliorate the current environmental crisis in human settlement.

Three institutions were designated, one each in Latin America, Asia, and Africa, to be responsible for the collating of existing information on standards and criteria within their regions. The Centre for Urban and Regional Studies of the Instituto Torcuator di Tella, Buenos Aires, Argentina was in charge of the Latin America region; the Institute of Development Studies of the University of Mysore in India took responsibility for the Asian region, and the Planning Studies Programme, University of Ibadan, Nigeria undertook the task for Africa.

Two types of standards were agreed upon: official and cultural. Official standards are those set by legislation, bylaws, rules, and regulations. Cultural standards relate to what is tolerable and acceptable to a large number of people. Criteria, on the other hand, are guides to standards arising from social values or recommendations as to levels of tolerance offered by professional or scientific bodies and based on published reports, case studies, and professional judgments.

In many developing countries and frontier areas, the conflict between official and cultural standards and the difficulties in enacting standards at social levels are influences which cause a relatively inefficient system of shelter provision. As a result, it was decided that the project should investigate both official and cultural standards. Official standards were to be investigated for each of the continental regions. Questionnaires were sent to appropriate agencies and individuals in various countries and followed up by direct visits. Cultural standards were to be investigated by surveys conducted in the countries in which each of the collaborating institutions is located.

However, for Latin America, it was possible to collate the necessary information for official standards only for four out of the thirteen countries: Argentina, Bolivia, Brazil, and Paraguay. Surveys for evaluating cultural standards were undertaken for two agglomerations in Argentina – Greater Resistencia and Greater Tucuman. In Asia, the investigation of official standards covered, apart from India, four other countries – Malaysia, Philippines, Singapore, and Thailand. Within India ten case studies covering six urban and four rural settlements in different parts of the country were undertaken. In Africa, information concerning official standards was collected in the following countries – Botswana, Egypt, Ethiopia, Ghana, Kenya, Nigeria, Sudan, Tanzania, Uganda, and Zambia. The investigation of cultural standards was limited to four settlements that have recently developed within the metropolitan area of Lagos.

The full result of this study appeared in a report by SCOPE to HABITAT, the United Nations Conference held in Vancouver in August 1976.

b. Existing Standards and Criteria

One of the interesting aspects of the study is the recognition of the varying degrees of governmental interest in matters concerning human settlement. In Latin America and Africa, governments have established official standards for shelter provision only in respect to urban settlements. In Latin America, the suggestion is that this is due to the fact that a high proportion of the population live in urban centres. In Africa, the situation is the reverse and the absence of any interest in non-urban shelter must be put down to inadvertence. Asia provides a wide spectrum of human settlement types and in a number of the countries official standards exist for both urban and rural types.

With respect to standards specifications, it was possible to identify three broad groups in the area of shelter provision. These are: accommodation, threshold, and technological (performance) standards. Accommodation standards define the level of intensity with which a particular activity such as housing construction may be conducted. The unit of expression varies. It embraces such units as building space, number of persons or buildings per unit area as well as space standards for community services and similar activities since these can be viewed as standards limiting the intensity to which a particular piece of land is put to a particular use. Of the different accommodation standards, those for occupancy, density, and minimum accommodation are of considerable environmental importance.

Threshold or range standards define lower and upper limits of populations, area or distance serviced by a particular amentity or a community service. These may range from standards regarding the per capita supply of water, the desirable number of students to support a school, the number of shops, to the size of a recreation area required for a specific size of population. Range standards define the maximum distance to as well as the maximum area serviced by a facility while threshold standards define the respective minima.

Technological or performance standards define the quality of environment such as the quality of construction, use of materials, quality of services, or tolerable levels of toxicity. Building bylaws, codes of construction, regulations on wastes, industrial effluents, fire, and noise, all tend to devote considerable amount of space to these types of standards.

c. *Evaluation and Rationale*

In most of the countries investigated, the accommodation and performance types of standards were found in considerable detail in legislation. Only in a few countries, such as India and Zambia, were there many standards of the threshold type. However, because of the legal style in which most of these standards have to be specified, their scientific rationale was seldom stated beyond broad claims of health, safety, privacy, and easy accessibility. Attempts to investigate the scientific rationale behind a few of these standards revealed that either these were non-existent or, where they did exist, they had little or no basis in local experience. A good example are the standards on day-lighting in tropical countries of East Africa, where given the latitudinal location, there is little likelihood of an insufficiency of light penetration into buildings. It appears that the common effort by the local population is to limit the degree of penetration. Yet, in Kenya and Uganda, the standards specify that for day-lighting, the area of windows in a house must be at least 10 percent of floor area and the windows must open to open spaces. Such a standard, which is more appropriate to high latitude, temperate countries, comes to affect the density of buildings allowed per unit area.

A few other factors do affect the nature and rationale of standards which were encountered in the three regions in the field of shelter provision. One such factor is the absence of any definitive and clear governmental policies on the issue of shelter provision for the masses. It is typical to find statements in the development plans of many of these countries which indicate governmental determination to build a certain amount of low-cost housing at a given amount of money. When the agencies saddled with this responsibility realize the difficulty of matching the number of units to be built with the actual funds available, one of the variables that they manipulate is the standards, particularly the accommodation standards. In such situations, the enforcement agency itself may already be party to this manipulation or may find itself incapable of enforcing compliance with the official standards against another governmental agency. In short, a common feature of official standards setting and enforcement in most developing countries is the multiplicity of agencies involved in the operation.

This situation becomes more complex when foreign or international agencies are also involved in financing the provision of shelter. Especially in Latin American countries, their definition of criteria for approving building loans to individuals or governments invariably implies the establishment of standards which in many cases have no relevance to environmental conditions in the countries or to actual needs of the people.

Most of the standards tend to be characterized as minimum. For most of the countries, given the average level of income, the minimum standards are often unattainable for the masses. This is particularly true with respect to technological standards. In most countries, technological standards for walls are defined in terms of stones, bricks, or concrete blocks. In the Ghana regulations, for instance, it is stated that bricks or blocks used in any wall shall be composed of sand-cement, soil-cement, concrete, burnt clay, or sand line and have a resistance to crushing at 28 days of not less than 400 pounds per square inch of gross horizontal area where the wall is for a small house, 1,500 pounds per square inch if bricks and blocks are solid, or 750 pounds per square inch if bricks and blocks are hollow. Yet, Ghana only began to produce cement locally in 1967 and even now imports a high proportion of its consumption. An unrealistic set of standards in the provision of shelter can adversely affect a country's balance of foreign payments. Naturally, since people must satisfy their shelter needs somehow, the tendency is to ignore any governmental guidelines in this matter and thereby challenge government to react. Not unexpectedly, governmental response has in many instances been one of indifference at the numerous but less conspicuous instances of non-compliance.

The operation of relatively high minimum standards implies the acceptance of a process of social stratification in the thrust of governmental policy with respect to shelter provision. As long as these standards and criteria continue to be enforced in their present form, it is unlikely that shelter can be provided for other than the middle and upper income groups in most developing countries. The vast majority of the population would therefore be constrained to seek solutions to their shelter needs outside official guidance, using technology and material whose appropriateness and adequacy can be made flexible and adaptable to their changing needs and resources.

Already, a few countries are trying new methods of setting standards. One such method, based on housing-user surveys, has been used in Egypt and the Sudan. Descriptions of different types of house construction using various material and design specifications are given to occupants whose levels of satisfaction with different aspects of the building are investigated. In other places, research on the functional efficiency of various materials provide an initial basis for the hope that realistic changes may occur in the setting of standards and criteria for shelter provision in developing countries.

d. The Emergence of Policy

In attempting to evaluate the present situation with respect to standards and criteria for shelter provision in developing countries, certain basic issues must be emphasized. The first is that developing countries are experiencing an unprecedented rate of urbanization. The millions of people who are moving from their normal rural abode to seek new residences in cities give the question of shelter provision a poignant urgency. It is evident that there is considerable diversity within this urbanizing situation which makes the shelter-environment issue assume different dimensions in different countries.

A second issue is that, almost without exception, developing countries have not seriously considered the implications of development. Everywhere there is a lack of explicit urban and housing policies. Low priority is given to the problems of shelter provision. In the absence of such policies, standards and criteria tend to be enforced in a vacuum since there is no overriding basis for validating their effectiveness as implements of desired national objectives.

The SCOPE project underlines certain aspects of shelter provision which need to be given high priority in the development of urban and housing policies, especially if the shelter needs of the total population are to be considered. The starting point for this consideration is the assertion that in the foreseeable future most of the shelter in developing countries will be self-built. This realization must direct attention to the formulation of policies which would assist rather than hinder the ability of the majority of the population to minister to their own needs directly. It should also underline the need to develop standards and criteria which are simple to implement and whose rationale and relevance are easily appreciated.

A second point of crucial importance is the consideration of shelter more as a process than an object. For the majority of the population in developing countries, shelter is an incremental product reflecting stages in the socio-economic mobility of its owner. This consideration immediately points out the conflict inherent in an existing situation where static standards are being applied to a dynamic process. It is often clear that when the masses of the people are engaged in providing their own shelter, the end position of their effort is not easily identified. The problem of how to develop a set of rolling standards which can reflect current capabilities confronts the scientific community with some challenging tasks in the shelter-environment field.

Given these two facts concerning the future prospects of shelter provision, a primary area of policy development for governments in developing countries is the provision for the masses of building plots for which the right of occupation is guaranteed. In many studies that have been conducted to date, it has been shown that the positive environmental effect of a sense of secured tenure has been considerable. The confidence deriving from the knowledge of undisturbable occupation has led many migrants in cities to devote tremendous resources to improving their shelter while striving to maintain an appreciably high quality of the environment.

One other important consideration that needs to be emphasized in policy concerns the relationship between available natural resources and current standards for shelter provision. Unless there are tremendous new mineral discoveries or a dramatic technological break-through, it can be stated unequivocally that it is impossible for developing countries to provide shelter for the masses of their population on the basis of existing standards. To attempt to do so would lead to a rate of depletion of natural resources that is hardly imaginable. If India, for instance, is to build all its shelter with cement, it is estimated that it will need more than current world production of this commodity. The economies of most developing countries are unlikely to be able to bear the level of expenditure that will be required for such a purpose.

Given this fact, a novel way of looking at the issue of standards is to redefine it within the framework of an equitable distribution of national resources among citizens. Such a reconsideration brings to the forefront the concept of maximum as opposed to minimum standards. This concept requires that a maximum limit be set to the amount of land and material that any individual can consume in the process of shelter provision while assuming that with a minimum of guidance the vast majority of the population can exercise good sense in the provision of shelter for themselves.

The concept of maximum standards may appear revolutionary until some of its rationale is appreciated. For instance, setting maximum standards to space or material use in the provision of shelter will ensure that more resources are available to the majority. It also raises the probability that many more of the masses can attain current so-called minimum standards in their shelter provision. Moreover, the implementation of maximum standards is sure to cut down on wasteful uses of resources while at the same time considerably improving the efficiency of human settlements.

Furthermore, the operation of a maximum standard may provide new and vast opportunities for the construction industries to build many more housing units rather than concentrating on producing expensive and relatively luxurious dwellings for the few. Such opportunities can, however, only be seized if the problems of appropriate technology and suitable material are first resolved.

e. Conclusion

The present SCOPE project on standards and criteria has underlined a significant fact about shelter provision in developing countries. This is the incompatibility of present policies or lack of policies with the maintenance of a desirable level of environmental quality. Current standards in many developing countries are foreign in origin, often lack a base in science, and continue to depend on technology and organization structure which make them unable to provide the shelter needs of the majority of the populace.

Yet, in terms of shelter needs, it is important to ensure considerable flexibility in the setting and enforcement of standards. Flexibility in this context should be interpreted as entailing much experimentation. Human settlement is the result of the culture and the resources of a country. As such, in order to be meaningful, standards and criteria must relate to current, or established modes of production. Flexibility therefore also involves providing broad guidelines whereby standards and criteria can be modified in the light of changing modes of production.

Very little is known about the considerations which should aid in developing such guidelines. There is almost no information as to what type of cities can be built by different economies using different technologies. Even less information is available on the bio-psychic limits of human endurance within the shell of a shelter. Any theoretical approach to human settlement must be policy-oriented if it is to catch the significance of the current crisis in the provision of shelter. All these and many more problems compete for the attention of the international scientific community in its consideration of the environmental aspects of human settlement.

CHAPTER 5

Activities of the International Council of Scientific Unions (ICSU)

The major issues of environmental concern and management cut across the boundaries of established scientific disciplines. Constructive responses to them rest upon analysis and synthesis of evidence flowing from research in all those sectors of physical, biological, and social science applicable to environmental systems. Because none of the issues is the exclusive province of a single discipline, the scientist from a variety of fields must find improved modes of collaboration if the responses by professional groups and governments are to be sound and balanced. In this chapter we review the activities already in progress under ICSU auspices. In the concluding chapter we suggest initiatives which ICSU should take in strengthening those efforts.

The wide-ranging work of the ICSU family encompasses the individual international unions such as the International Union of Pure and Applied Chemistry (IUPAC), its scientific associates such as the International Society of Soil Science (ISSS), and its special and scientific committees, such as the Scientific Committee on Oceanic Research (SCOR), that deal with problems of particular areas or are multidisciplinary. Mention of parts of the SCOPE effort was made in passing in the preceding chapters. It is placed here in the perspective of the whole, diversified concern of ICSU. The programmes of the chief ICSU activities in the environmental field are summarized in Appendix B, and the participants in the SCOPE Mid-term Programme are listed in Appendix C. Without presenting the details that may be found in those appendices and without a fully deadening array of acronyms, it is useful to show how the programmes of unions, associates, and committees are related to the issues presented in this report, and which research topics currently receive attention.

The basic concern with world and climate change among scientists is central to the Global Atmospheric Research Programme (GARP) as it has developed as a joint enterprise of the World Meteorological Organisation (WMO) and ICSU. Through GARP's initiative, long-term studies are directed at those physical processes of the atmosphere that are essential to understanding large-scale fluctuations which control changes in weather. This includes collaboration in the modelling of atmospheric systems, and the planning of observations in areas where data are lacking. For these purposes major computational and weather observation facilities and mobilized among governments and research institutions, and special symposia are directed at the questions outlined in Chapter 3C.

In addition to the GARP efforts, the Special Committee on Solar-Terrestrial Physics (SCOSTEP) sponsors the investigation of possible correlations between solar-terrestrial physical phenomena and meteorological and climatological patterns. The capacity to make meteorological observations at lower costs and with greater comparability is enlarged by the work of a panel of the Committee on Space Research (COSPAR) which evaluates the utility of space-based measurements. The question of what accounts for the photochemical equilibrium of the ozone layer receives attention from another COSPAR working group.

For two large areas of international concern, multidisciplinary groups are pressing for more refined understanding of climate. In the southern polar region the Scientific Committee on Antarctic Research (SCAR) brings together groups of specialists on meteorological, geological, and glaciological processes related to climate, including changes that occurred during the late Cenozoic period. In the oceans, the Scientific Committee on Oceanic Research (SCOR), sponsors exchange of data and scientific analysis dealing with climate, air-sea interactions, and tropospheric transport of contaminants.

The International Union of Geodesy and Geophysics (IUGG) and especially its affiliated Associations of Meteorology and Atmospheric Physics (IAMAP), of Geomagnetism and Aeronomy (IAGA) and of Hydrological Sciences (IAHS) are active in these scientific areas.

The nature of the great cycles of chemical constituents in air, water, soil, and organisms commands the interest of several unions and committees. Beyond the initiatives taken by SCOPE in a general symposium on biogeochemical cycles sponsored by its USSR national committee, special reviews of nitrogen, phosphorus, and sulphur were made under the auspices of the Swedish national committee (described in Chapter 3B), and carbon and oxygen balance were examined in a preliminary fashion by the US national committee. All such activities draw upon the knowledge of magnitudes and rates of material flows that is fostered by the International Union of Theoretical and Applied Mechanics (IUTAM). Because of deficiencies of both data and knowledge of the transport processes, it is difficult to construct mass flow models, but the Swedish report on sources, sinks, and flows of nitrogen, phosphorus, and sulphur illustrates the directions to be followed in quantifying nutrient cycles on a regional or global basis. Criteria and methods for the accurate description of spatial distribution of the macro- and micro-elements in the biogeochemical landscape are the subject of a review sponsored by the Belgian national committee.

Concern for pollutants in the environment extends from consideration of the basic processes of transport to examination of evidence on effects in organisms. IUTAM is involved in appraisal of mathematical modelling of the dispersion of contaminants, including noise, from sources to receptors, through air, water, and ground. The International Association on Water Pollution Research (IAWPR) fosters examination of all aspects of water pollution control or abatement in surface, underground, and marine waters. Long-term changes in water quality are assessed by the Scientific Committee on Water Research (COWAR), and the pollution of the Baltic and tropospheric transport of pollutants are subjects of SCOR activities. Possibilities of using space-based facilities to detect various pollutants and the distribution of biological indicators that are sensitive to pollution are investigated by COSPAR. The International Association of Acoustics of IUPAP co-ordinates acoustic research on noise pollution problems.

A state-of-the-art review of ecotoxicology, as illustrated in Chapter 3D, is under way by SCOPE with support from the national committee of the Federal Republic of Germany and of the Commission of the European Communities. This concentrates on principles in planning research projects in ecotoxicology, and covers the environmental behaviour of pollutants, experimental toxicology, field observations, dose-effect relations, and overall estimation of ecosystem effects.

Growing out of early SCOPE investigations, a plan for an International Registry of Potentially Toxic Substances was developed, and later incorporated in the United Nations Environment Programme (Levinthal 1976). The discussion by the US national committee of lack of solid information as to movement of toxic substances in the environment, led to initiation of a programme for monitoring of ocean and coastal pollution through analysis of accumulator organisms, chiefly *Mytilus* sp. (Goldberg 1975). Thus, reviews of state of knowledge of contaminants can stimulate new research, new outlines of research procedure, and enlargement of the presently small data base.

In seeking understanding of human impact upon renewable natural resources, the ability to assess dynamic change in ecosystems is pursued by various sections of the International Union of Biological Sciences (IUBS). Work which helps specify population structure and tolerance to perturbation of component species yields useful information. Under commissions of the International Geographical Union (IGU), evaluations are going forward on rates of geomorphic change in various environments, on the advance or recession of the world's shorelines, and on desertification processes. Possible impacts of mineral or other exploitation on the Antarctic environment are studied by working groups of SCAR.

Integrative views of ecosystem change are sponsored by the International Association for Ecology (INTECOL). These focus on agro-ecosystems within the total landscape. The evaluation of current knowledge of ecosystem processes (Chapter 3E) grew out of a workshop sponsored by MAB in co-operation with SCOPE, and with partial support from the Ford Foundation. It reviewed present concepts regarding ecological succession, methods of modelling and prediction, and applications to management of forests, rangelands, and other near-natural ecological systems.

The International Society of Soil Science (ISSS), in collaboration with FAO, UNEP, and UNESCO, conducts a global assessment of land degradation in cultivated and grazed areas. Under a collaborative arrangement among UNESCO, SCOPE, and COWAR a joint working group prepared an appraisal of what is known concerning environmental effects of irrigation and drainage, as reported in Chapter 3E. In a broader framework, SCOPE in co-operation with its Canadian national committee carried out a review of the scientific issues involved in assessment of environmental impacts. This resulted in a report which examines available techniques, their strengths and limitations (SCOPE 5).

An aspect of renewable resource management of vital importance to future land use is the conservation of genetic diversity. Currently or recently used cultivars and special genetic stocks are generally adequately represented in collections. Obsolete cultivars need more attention, but the greatest problem is posed by the perpetuation of primitive varieties and of related wild species as sources of resistance to diseases and pests. Reasonably representative samples of the variation in crop cultivars can be conserved economically as seed since the optimum storing condition for many seeds is known. Gene banks have been established all over the world under FAO auspices to preserve most important crop plant varieties and their wild relatives. With the Consultative Group on International Agricultural Research (CGIAR) a plan is under way for a worldwide network of genetic resource centres co-ordinated by the International Board for Plant Genetic Resources (IBPGR).

The greatest problem of genetic resource conservation is gene erosion, or genetic drift. The genetic variation of sexually reproducing wild species is extremely large, and if this variability is to be maintained, millions of individuals would have to be preserved in gene banks. Such large-scale preservation is clearly impossible. An alternative solution is in situ conservation in national parks and biosphere reserves established under MAB. Perhaps one half of the wild species of the world might be included in such reserves. Keeping their genetic diversity, they would be able to evolve in response to environmental change and remain available for scientific studies or breeding programmes.

As noted in Chapter 4A, problem identification and monitoring embraces a large variety of activities joining scientific research with environmental decision-making. On the methodological side, the statistical aspects of monitoring network design and sampling grids receive attention from IUTAM, and COSPAR examines the feasibility of space-based observation systems for atmospheric phenomena, natural resources, and pollutants. The selection of appropriate sites for observations in Antarctica and the oceans is investigated by SCAR and SCOR.

On the data side, several global efforts have sprung from planning by ICSU units. The Middle Atmosphere Programme provides a co-ordinated observation of the region from the tropopause to the top of the mesosphere. Another programme monitors solar-terrestrial physics data. A plan for monitoring human malnutrition is in course of preparation by the International Union of Nutritional Sciences (IUNS).

Under the auspices of SCOPE, a group of scientists have joined at Chelsea College, University of London to provide capability for problem identification and monitoring as outlined in Chapter 4A. Known as the Monitoring and Assessment Research Centre (MARC), the group pursues several themes developed in workshops at Stockholm and London during 1974. It is occupied with the characterization of monitoring data, the concept of environmental dose commitment, the concept of resilience, cost-effective analysis of monitoring systems, the time perspective of environmental change, indices of environmental quality, and related training. MARC is supported by UNEP, the Department of the Environment of the United Kingdom, and the Rockefeller Foundation.

Modelling of environmental systems claims the interest of working groups throughout the ICSU family. For example, the simulation of physical and biological processes by high-speed computing methods, and mathematical modelling of dispersion of pollutants are topics for IUTAM units. The GARP concern with global atmospheric modelling includes programmes on numerical experimentation and parameterization techniques in numerical models. Modelling of oceanic processes is addressed by SCAR. Agricultural systems are modelled by a commission of the IGU.

To bridge some of these compartments, SCOPE is carrying out a state-of-the-art assessment of environmental models for use in policy decisions. This activity, reported in part in Chapter 4B, draws upon workshops held in Indianapolis and Moscow, and incorporates experience from Australia, Canada, Egypt, the Federal Republic of Germany, Japan, Nigeria, the UK, the USA, the USSR, and Venezuela. It is supported by the Holcomb Research Institute.

Risk estimation probably has been developed most fully in connection with the hazards from radiation. A commission of the International Union of Pure and Applied Biophysics (IUPAB) is engaged in assessing biological hazards with a view to a comparative statement on organism tolerances and maximum permissible levels of radiation. A more general comparative analysis of risk assessment methods was prepared by SCOPE with the support of UNEP and the Electric Power Research Institute (SCOPE 8 1976). Based upon a workshop at Woods Hole, the analysis deals with problem identification, risk estimates, and evaluation, as noted in Chapter 4C and D.

Problems of evaluation and communication of scientific findings on environmental matters tend to receive only incidental attention in ICSU activities. For the reasons outlined in Chapter 4D the scientist tends to assume that the new information somehow will reach the right people who will use it intelligently. SCOPE's Project VII brings together research workers and people involved in policy formation to examine the difficulties attached to the actual use of scientific evidence in decisions on the environment. In this it builds upon earlier experience with examination of public policy implications of knowledge as to ecosystem modifications by man-made lakes (SCOPE 2), and of environmental impact assessment (SCOPE 5).

Aspects of standard setting, like other processes of environmental decision-making, are receiving critical review. The IUPAB appraisal of radiation standards is one such effort. Another is the periodic examination of water quality standards by IAWPR. The problem of suitability of housing design requirements for developing countries, as reported in Chapter 4E, is studied by SCOPE working with research institutes in Argentina, India, and Nigeria. Other standards are touched upon in the course of ICSU activities in the fields of biology, chemistry, and pharmacology, but systematic appraisals of their suitability to conditions in developing countries rarely are made.

The above review omits numerous details which may be found in Appendices B and C or in publications cited from the responsible ICSU units. Albeit brief, it serves to outline the diversity and extent of ICSU activities in the environmental field. The bulk of them are in the basic disciplines represented by the unions. To an increasing degree, in investigating oceans, the Antarctic, or atmosphere, they take interdisciplinary approaches.

PART III

The Future

CHAPTER 6

A Forward Look

A. GENERAL PERSPECTIVES

The central message of this report is that scientists have come to recognize the escalating impact of mankind on the world. The principal lesson is that human power to disturb the environment has run ahead of the methods for assessing and responding to the environmental impact of contemporary and prospective human activities. There is a clear and pressing need to put the scientific house in order and to develop the fundamental knowledge on which wiser policies for managing the environment must rest. The conduct of the next few decades will assuredly determine the environment for a century or more, and we believe that the effective communication of scientific knowledge can do much to guarantee its quality.

The tone of this report is one of cautious optimism. There are already many examples of the application of scientific understanding to the wise management of natural resources. More information is needed about the functioning of environmental systems and of their response to the perturbations introduced by human activity. Better communication is needed between scientist and policy-maker. If these needs are met, there is certainly no reason to despair, but neither is there ground for complacency.

Addressed to the ICSU family, this report suggests some of the actions which the world's scientific community might well take over the next quarter century in order to help the human community to move forward in balance with its environment. It takes a long perspective because only recently have human activities become comparable in scale with natural factors in their impact on the world environment. Those impacts certainly will not all continue to grow at the exponential rate many have displayed in the recent past. Equally certainly, however, the proportionate influence of man and of natural factors will continue to change in the direction of human dominance, at least over the next century, when the urban populations in developing countries are certain to expand greatly and when technology will certainly increase human capacity to perturb the cycles and processes of the natural world.

This escalation of human influence during the past few thousand years has been characterized by the development of social philosophies as well as scientific knowledge. Religions have been preoccupied with man's place in the world. The emergence of cosmological and astronomical science placed human society in its position in relation to the vast scale of the Universe. The parallel but later expansion of biological science allowed people to relate the short period of human culture to the long preceding period of organic evolution and emphasized that, despite recent advances, human societies are still to a considerable extent governed by biological processes.

In this report, Chapter 1 provides a conceptual framework emphasizing some of the dominant features of the natural world. This framework embraces:

(a) the total dependence of life on earth on the sun and on the production of plant matter using solar energy,

(b) the overwhelming importance of the natural cycling of nutrients in the environment and the profound effect of its modification by man,

(c) the increasing capacity of science to control the life cycles of organisms and develop new strains capable of enhanced productivity,

(d) the increasing capacity of medical science to protect human life and alter the balance between man and pathogens, and

(e) the increased capacity of modern man to acquire, analyse, and present information. This capacity allows societies to blend the individual contributions of enormous numbers of individuals on an unprecedented scale, extends human intellectual capacity, and presents the potential for the community to respond as a collective, intellectual entity.

The interactions of man and environment inevitably demand, if they are to be understood, the fusion of many scientific disciplines. The problems of the environment are wider than most that confront individual ICSU unions. They challenge ICSU to respond with similar breadth. It is essential that fundamental scientific knowledge in various specialist disciplines continues to advance, for without real depth of basic information the syntheses undertaken by groups concerned with interdisciplinary problems of the environment will be limited in accuracy and penetration. This report assumes that ICSU unions will continue to promote basic scientific research: we do not, therefore, propose priorities within individual disciplines. We do, however, emphasize that without that support, the integrative activities will have diminished value.

B. MAN AND ENVIRONMENT

The core of our thesis, and the centre point in the future activities of SCOPE, lies in the recognition of a fundamental need to understand the relationship between people and their environment. It is not sufficient simply to analyse the biological and medical factors that limit the reproduction, growth, health, and well-being of individual human beings. We speak in this report of the need to evolve humane and flexible population policies, but these are only a part of the total requirement. The fundamental interaction is between the numbers of people and the activities which those people pursue on the one hand, and the resources of the environment available to them on the other.

The importance of this interaction for human well-being, fitness, physical development, and working capacity has emerged from the studies conducted in the human adaptability section of the IBP for a large number of human groups living in a wide variety of habitats and climatic regions. (The IBP Synthesis Volumes are being published by Cambridge University Press.) This interaction is highly dynamic and it varies from region to region in the world, not only because natural environmental resources vary but also because the activities of people are themselves influenced by history and by cultural and ideological outlook. There is unlikely to be any single ideal human population density, even in regions with comparable environmental conditions, for what is considered ideal is a value judgment moulded by social, historical, and cultural factors. WHO retains the major responsibility for promoting the health of mankind and FAO for surveillance of its nutritional state: SCOPE's contribution might be to inform the choices of the various communities by making available to them a better scientific understanding of the factors which have in the past limited the numbers of humans under natural conditions and of the environmental variables which must to some extent constrain social choice. Options can be stated. How communities respond to those options is a matter for informed choice in the light of the prevailing social, physical, and biological circumstances.

C. ACTIONS IN THE FUTURE

A scientific response to problems of this kind inevitably involves the consideration of environmental variables, aspects of human ecology, and aspects of human thought. All are interdependent as this report shows. In the future there is a clear need for data acquisition processes that will not capture large quantities of irrelevant or low quality information incapable of useful analysis, but will permit critical environmental assessment and evaluation leading through improved communication systems to wiser judgments. The process of modelling is an essential element in the changing human and environmental situations, and is essential feedback to guide the processes of data acquisition. In all these activities, we must recognize that the fields of environmental concern may change. Those into which we have divided this report in Chapter 3 will certainly prove ephemeral and would have been different had we written this report two or three decades ago. On the other hand, we believe that the classification of basic responses we have used in Chapter 4 is likely to be enduring. Processes of problem definition, monitoring, modelling and analysis, risk assessment, evaluation, communication, and social response have characterized human societies for many generations, even if not thus identified in terminology, and will almost certainly be identifiable a century hence.

D. SPECIFIC ACTIONS

We consider that it is essential in the decades ahead that the type of work we have described in this report continues. We see particular need for the following.

(1) Further research on the elemental cycles, especially of carbon, essential plant nutrients, and potentially toxic substances. It is becoming evident, not only that the present composition of the atmosphere and pattern of these cycles is the product of life, but also that many substances commonly treated as pollutants, such as methyl mercury or halocarbons, may occur naturally. Without an understanding of natural cycles and transformations, research findings on pollution will not be easy to interpret.

(2) Critical studies of the relationship between the exposure of organisms to levels of potentially toxic substances and their response. This will increasingly need to benefit from the application of mathematical methods and modelling in order that the biological grounds for the process of risk assessment can become more precise. It will also be necessary to extend work done on the toxicology and ecology of individual species to studies at the ecosystem level.

(3) Ecosystem description, analysis, and modelling. This will continue to be a subject of high priority. It is becoming apparent that it is impracticable to model every component in a complex ecosystem in a deterministic fashion and for this reason probabilistic models are likely to be adopted.

(4) Research on the adaptability of species and of ecological systems. This is important both because of expanding human impact and because ecosystems regulate the character of large areas and even affect global processes. For example, the methane generated in anaerobic wetlands may be an essential regulator of atmospheric oxygen levels. Studies of the resilience or inertia of ecosystems in the face of perturbation, and of the role of a small proportion of key species within them in determining the characteristics of the whole, will gain in importance as areas at present little used by man come under development pressure.

(5) Research related to the inescapable need to improve the food production of the world. This must involve not only the continued application of methods of soil conservation, irrigation, and fertilization, established agricultural and crop protection policies and well-tried genetic methods, but also innovative techniques. Advanced methods of crop and livestock breeding, including genetic engineering, carry with them the possibility of even more profound alterations in the ecology of the world than hitherto. Many areas at present remaining under relatively unmodified ecosystems are in this condition because it has not yet proved possible to crop them in an efficient fashion. As world population increases and the need to enhance food production grows with it, we expect that efforts will be made to develop strains more appropriate to marginal regions and thus expand the area of the globe intensively managed by man. It is important that large and diverse gene pools and an adequate series of protected samples of the world's diverse habitats are maintained as an essential source of such strains.

(6) More thought about the problems of human settlement. Although essentially socio-economic, these problems touch on such issues as the rational use of renewable and non-renewable resources and the improvement of traditional skills and technologies. People's basic biological needs and the factors that limit their adaptability and well-being, will require study along with analysis of means of satisfying the basic needs of adequate shelter and a living environment in which creative potential can be realized.

(7) An assessment of how population growth and development will affect the way in which both the renewable and non-renewable resources of the world are used. As demand increases, and the availability of energy sources alters, resources not at present considered exploitable may come into use. Rising costs are expected to favour the recycling of many materials at present dispersed into the environment as waste. There are likely to be shifts in the balance of resource consumption between nations. Like the issues of human population discussed earlier in this chapter, scientific considerations are only some among the many involved in this complex socio-economic picture. Research aimed at predicting more exactly the potential resources of different areas and developing technologies for the wiser use of conventional and new materials and energy sources will be of paramount importance.

(8) Development of rigorous and objective methods for environmental impact and risk assessment. Those impacts having potentially serious consequences which cannot be predicted precisely at present levels of scientific knowledge, are of special concern. Methods of risk assessment are being developed to meet this need and require further attention. The minimum needs are for methods of determining risk levels, of comparing risks of different sorts, of comparing risks and associated benefits, and for examination of differences between actual risks and perception of those risks. Special efforts are needed to ensure that scientific assessments reach policy-makers and the general public effectively. The aim is to improve the response of societies, in both public and private policy. The study of man's impact on the environment must proceed at many levels. Global studies should be done in partnership among major international agencies and ICSU Committees and Commissions such as COSPAR, SCOR, and SCAR. Regional and local studies should also be undertaken by coalitions of appropriate groups, international and national.

(9) Continued study of man's impact on the climate of the world, and climatic influences and constraints on human activity. The application of mathematical models, employing the very large capacity of modern computers in forecasting and in data analysis will clearly carry with it the possibility of much wider adjustment of human activities to the climatic vagaries of the world. There is also the risk of increased vulnerability to catastrophic events. It is essential to relate studies of man's impact on climate to the studies of likely future energy demand. We foresee a need for much more research on

the processes of interactions between living and non-living systems of atmosphere, land, and ocean, linking climatic research with that on the global cycling of essential elements.

(10) A more considered approach to environmental education within the context of efforts to improve communication between scientists and policy-makers. The need for such education in many countries is unquestioned, but it must not be pursued uncritically. In many countries Universities and Colleges have responded to the widespread demand among young people for a career in environment by creating broad courses which bring together fragments from many subjects. These courses all too often provide superficial acquaintance with the field, without the depth or discipline which make students employable or truly effective. Disappointment and waste of precious human resources result.

(11) Evaluations of the existing genetic diversity of the biosphere, the expected further loss, and the minimum gene pool and recombination needed in order to respond genetically to the likely future changes of the environment.

Many of these activities will need to be pursued by bodies other than SCOPE, and the final selection of SCOPE's own programme will be made following wider discussions within ICSU and with intergovernmental and other organizations so that the scarce resources of scientific manpower in the world can be most effectively deployed.

E. RESPONSIBILITIES OF THE SCIENTIFIC COMMUNITY

This report is inevitably written from the standpoint of a scientific committee of ICSU. However, it must not be forgotten that the strongest links of the scientific community are within respective national social systems, and that scientists must continually respond to national needs (especially in developing countries where there is a critical shortage of expertise). It is through this national experience that SCOPE is most likely to identify priority topics. The national scientific academies presently lack a regular means of exchanging their findings and comparing their judgments on environmental issues. The scientific community as a whole and the policy-makers of individual nations stand to gain from speeding up the flow of information and conclusions among them. SCOPE General Assemblies should provide a forum for the national committees in that effort.

Drawing upon national support, the ICSU unions and scientific committees can make great contributions to the solution of environmental problems through both the application of knowledge and experience to specific problems which permit immediate solution, and the improvement of the basic understanding of physical and biological phenomena. Union activities include pure, theoretical, and applied sciences and contribute to more than one level of scientific achievement.

Environmental problems involve interdisciplinary studies, and it was in order to promote a better interdisciplinary co-operation within ICSU and to identify those fields of environmental scientific research which individual unions, committees, and commissions could develop, that SCOPE was founded. Looking ahead, SCOPE can continue to provide this synthesis. It must not duplicate studies more logically undertaken by other ICSU bodies or by intergovernmental agencies. For example, it does not seek to embark on an active field programme like the Man and Biosphere programme of UNESCO.

In the future, SCOPE expects to use a series of ad hoc working groups examining the current state of knowledge about selected major issues, such as some of those in paragraphs (1)–(11) of the preceeding section and to publish periodic reports that will aid research and policy at national or international level. Where appropriate, a national committee will take responsibility for organizing a working group with the collaboration of unions and other national committees. The workshops in many instances will need to be supplemented by projects which will mobilize the enthusiasm of young scientists and enhance their capacity to synthesize complex findings and communicate the results. SCOPE thus aims to sharpen expert non-governmental thought about major environmental issues defined within its own organization or referred to it by international agencies. The results of these investigations may be presented in publications and at symposia, bringing together representatives of the relevant ICSU unions, committees, and commissions.

If the practice of interdisciplinary appraisal of salient environmental questions were to be put on a regular basis by ICSU there would be merit in a periodic assessment of the resulting findings and of their implications for national and international policy. The periodic assessment would give coherence and balance to the activities of the ICSU family.

In these two ways ICSU should strengthen its capacity to review environmental questions that cut across the traditional concerns of many member bodies, and to examine major global or regional problems. ICSU could well, through SCOPE or through other bodies, serve as a translator of the considered evaluation of world scientific opinion to users at national and international levels who need such evaluations as a guide to policy.

Evaluations, like the present report, are unlikely to set forward conclusions that will stand for all time. Priorities for environmental research are bound to change. The priorities of one region of the world will differ from those of another and from time to time. In this connection, we would emphasize one general point which emerges from this report. It is that there is a danger in the construction of simplistic global models of environmental problems and interactions. The most productive activity is almost certainly in the production of more local models which relate man, resources, and human activities under the particular circumstances of individual countries or regions. Ultimately, it should be possible to build these local models into a wider, aggregated model for broad regions, if not for the planet as a whole. Future activities should be centred upon the production both of these rigorous local analyses and the development of a more general conceptual framework which will allow their aggregation.

Scientists are not alone in the world and are only some of the specialists in a complex society. It is clear that the problems of the environment demand the synthesis of the results of many sciences and many specialities. It is equally clear that they will be of little value unless they are communicated to people other than scientific specialists in a fashion that permits careful weighing of the social value of evidence and of probabilities. The environment of the future is not being moulded by scientists but by policy-makers in government at national and local levels who draw on the expertise of scientists, economists, engineers, and many other professionals, but who are also to a very large degree influenced by the history and traditions of the communities in which they live. It would be foolish to assume that the scientist single-handed could revolutionize the thinking of all his fellow men and it might indeed be dangerous were he readily able to do so, for the generalizations of the scientist have not been completely reliable in the past.

The communication between scientist and policy-maker, stressed in this report, should continue to receive a great deal of attention in forthcoming years. This may mean that scientific data, acquired by using rigorous observational techniques and analysed using the advanced skills of the modeller and the capacity of the modern computer, will nonetheless need translating into a format very different from that of the computer program or the scientific paper before they can be used to arrive at judgments in a policy formulating sense. It is likely that both policy-maker and scientist will need to debate together in some depth just how this information can best be presented and appraised. We have no doubt that it is as vital to secure advances in this field as it is vital in the field of basic scientific information capture which has traditionally preoccupied us and our colleagues in the past.

APPENDIX A

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APPENDIX B

Activities of ICSU Unions and Associated Scientific Groups relevant to this Report

INTERNATIONAL ASTRONOMICAL UNION (IAU)

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As a part of its study of all phenomena in outer space, the Union has immediate concern with the identification and preservation of remaining sites for dark sky optical stellar astronomy. It maintains close contact with UNESCO and ICSU, and co-sponsors a number of meetings organized by other ICSU bodies (Contopoulos, 1974a, 1974b; Contopoulos and Jappel 1974). *IAU Information Bulletin* is published biannually and contains information on past and future meetings, symposia and colloquia, summary minutes, recent administrative decisions, publications, and personal notes. Twelve to twenty symposia and colloquia are held on specialized topics during each triennium. The proceedings of each has its own title and edition.

IAU has created a permanent commission for the study of the protection of astronomical sites, such as the Canary Islands, Baja California, and Mauna Kea, Hawaii. This commission met in August at the XVIth General Assembly of IAU in Grenoble, France. R. Cayrel of France is the newly elected chairman. M. F. Walker of USA is the past chairman.

INTERNATIONAL UNION OF BIOCHEMISTRY (IUB)

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USA

INTERNATIONAL UNION OF BIOLOGICAL SCIENCES (IUBS)

International Association of Ecology (INTECOL)

Professor G. A. Knox
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Christchurch, NEW ZEALAND

As a part of its concern with ecological investigations, the association advances the view that agro-ecosystems function as ecological systems; and promotes determination of similarities and/or differences in the regularities governing the ecological processes occurring in agro-, natural, and semi-natural ecosystems and assessment of the role of agro-ecosystems within the total ecological landscape.

It sponsors collaboration on problems of tropical ecology, ecology of small mammals, plankton ecology, and ecology of graminivorous birds.

It promotes comparative ecological analysis of urban environments (a co-operative project with MAB and UNEP) and study of the structure and functioning of human settlements as ecological systems.

It is organizing a working group on desert ecosystems.

INTECOL has sponsored numerous symposia including the Third International Symposium on Tropical Biology (Lubumbaski, Zaire, 1974), the First International Congress of Ecology (The Hague, 1974), and Biological Rhythms in the Marine Environment (Baruch Institute for Marine Biology and Coastal Research, 1975).

It publishes three journals, *Oecologia*, *Agro-Ecosystems*, and *Urban Ecology*, and a bimonthly *Newsletter*. The *Newsletter* includes reports of MAB programme activities and is distributed to ecologists in developing countries (Golley and Medina 1975, Hasler 1975, Junk 1975).

INTERNATIONAL ASSOCIATION OF MICROBIOLOGICAL SOCIETIES (IAMS)

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Acting through its World Federation for Culture Collections (WFCC), which is also an IUBS federation, the association seeks to promote the preservation of microbial genetic resources as well as making these available to developing countries. Through its International Commission on Microbial Ecology (ICOME), also an IUBS commission, the association promotes microbial ecology and its environmental applications such as biological nitrogen fixation and waste utilization. IAMS, WFCC, and ICOME are actively involved in the work of the

UNEP/UNESCO/ICRO panel on microbiology which helps guide and implement the UNEP/UNESCO programme on the use and preservation of microbial genetic resources for deployment in environmental management. This programme organizes conferences and training courses and envisages the creation of a network of Microbiological Resources Centres in the three regions of the developing world.

INTERNATIONAL UNION FOR PURE AND APPLIED BIOPHYSICS (IUPAB)

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The union is involved in basic scientific research as well as seeking ways and means to use modern biophysical techniques for the solution of current problems in areas such as drug testing, medical physics, environmental pollution, energy conversion, desalination, enzyme and microbiological engineering, and genetic manipulation in plants and animals.

An important part of the union's activities lies in helping scientists in developing countries to learn and apply the sophisticated approaches on which the rapid advances of biophysics in recent years have often depended. This is done by holding symposia and summer schools in such countries, through the provision of travel funds for attendance at meetings held in the USA and Western Europe, by sending teams of IUPAB Lecturers to give seminars at appropriate centres, and by producing textbooks with their special needs in mind.

The union arranges an international congress covering the whole field of biophysics every third year, alternating with those of IUB and IUPS, while its scientific commissions sponsor specialized symposia at more frequent intervals, usually in conjuction with other organizations.

The official journal of the union is the *Quarterly Reviews of Biophysics*, published by the Cambridge University Press. This contains critical and up-to-date articles on a wide range of biophysical topics, written by authors who have made significant contributions to the subject. In addition, the Union sponsors a new series of Biophysics texts, also to be published in due course by the Cambridge University Press.

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY (IUPAC)

Professor G. Ourisson
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IUPAC covers the whole field of chemistry and fosters advances in that science. It operates under six main divisions, viz. Physical, Organic, Inorganic, Analytical, Macromolecular, and Applied. While several of these divisions are concerned to some extent with environmental matters, the Division of Applied Chemistry is particularly concerned with problems of environmental importance. Much of the work is related to methods of identification and analysis, and some with detailed chemical structure.

The following is a brief listing by title of topics under active study, arranged under general headings.

Food additives – Methods for collaborative study of non-volatile nitrosamines in food; methods for nitrite and nitrates in food; collaborative study of methods for multi-antioxidants in food; urethane in beverages; N-heterocyclic carcinogens in food; migration of PVDC derived from food packaging; residues in edible products from treated livestock; priority of study of analytical problems relative to food additive use.

Food contaminants – Collection of information on food contaminants derived from food packaging; determination of mycotoxin in foodstuffs; multi-mycotoxin analysis; use of animal waste for animal feed; determination of lead and cadmium in food; determination of copper in food; selenium in foods; determination of fluoride; single cell proteins; minicolumn methods for mycotoxins; mycotoxin formation during shipment of foodstuffs, sampling plans for mycotoxin analysis; mycotoxin residues in food of animal origin; TLC method for Ochratoxin; method of determination for afltoxin M2 in dairy products.

Oils and fats – Organochlorine pesticide residues in fats and oils; trace plastic polymers in oils and fats; contaminant plastics polymers in oils and fats.

Air quality – Reliability in air quality data; chemicals with long-term effects; chemicals of ecological significance; sampling strategy; calibration and verification of automatic monitors; evaluation of biological and air quality information; source identification of transition products and ultimate fate; characteristics of aerosols; sulphur acidic aerosols; organic isocyanates; metals in air.

Terminal pesticide residues – Insecticides (toxaphene, cyclodienes, carbamates, pyrethroids, organophosphates), herbicides, fungicides, fumigants; photodecomposition of pesticides, environmental significance of ETU, effect of food processing on pesticide residues.

Pesticide residue analysis – Organochlorines and organophosphorus compounds; fumigants; carbamate herbicides, insecticides and fungicides; systemic fungicides; other fungicides; organotins; rethrins; synergists; influence of post-harvest factors on the amount of residues; lower limits of residue analytical methods; statistical treatment of analytical data; selective GLC detectors; confirmatory tests for residues and metabolites; liquid chromatography; adsorbents and GLC-phases.

Water quality – Pollution abatement in industry; microbiological aspects of effluent treatment; nomenclature in water chemistry.

Reclamation of solid wastes – Identification of solid waste problems on an international basis.

Symposia and Conferences

Fifth International Fermentation Symposium, 28 June–3 July 1976, Berlin

International Symposium on Advances in Smoking of Foods, 7–10 September 1976, Warsaw

Third International Symposium on Mycotoxins in Foodstuffs, 16–18 September 1976, Paris

Third International Symposium on Genetics of Industrial Micro-organisms, 5–9 June 1978, Madison

Fourth International Congress of Pesticide Chemistry, 24–28 July 1978, Zurich

Sixth International Fermentation Symposium, 1980

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS (IUGG)

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The objectives of the union are to promote and co-ordinate physical, chemical, and mathematical studies of the earth and its immediate spatial environment. It has been a major participant in the activities of most of the international scientific programmes which ICSU has sponsored. In particular, the IUGG has been responsible for initiating the collaborative action which led to such intensive world-wide co-operative research programmes as the International Geophysical Year (1957–58), the Upper Mantle Project (1964–70), and, more currently, the Global Atmospheric Research Programme (1970–80). At the present time the IUGG is involved in the work of the ICSU Scientific Committees for Antarctic (SCAR), Oceanic (SCOR), Space (COSPAR), and Water (COWAR) Research, on Problems of the Environment (SCOPE), on Solar Terrestrial Physics (SCOSTEP), and several inter-union commissions including radiometeorology (IUCRM), geodynamics (ICG), and the planned co-ordinating committee on the Moon and Planets (CCMP). It is also represented on the Teaching of Science Committee (CTS) and on the Committee for Science and Technology in Developing Countries (COSTED). The IUGG gives particular emphasis to the scientific problems of developing areas by sponsoring symposia relevant to the scientific needs of the Third World (Geodesy in Africa, International Water Resources, etc.). The Union also co-sponsors the Federation of Astronomical and Geophysical Services (FAGS) and serves on the Panel for the World Data Centres (WDC's) as well as the ICSU Committee on Data for Science and Technology (CODATA).

IUGG contains 7 semi-autonomous international associations, each responsible for a specific range of studies within the overall scope of the Union's activities and each with a substructure. The disciplines covered by the associations are: Geodesy (IAG), Seismology and Physics of the Earth's Interior (IASPEI), Volcanology and Chemistry of the Earth's Interior (IAVCEI), Geomagnetism and Aeronomy (IAGA), Meteorology and Atmospheric Physics (IAMAP), Hydrological Sciences (IAHS), Physical Sciences of the Ocean (IAPSO).

The union and the associations publish information bulletins periodically as well as the proceedings of meetings of the associations and of symposia sponsored by the associations. The following bulletins are issued by the union and the associations which also publish more specialized bulletins from time to time (data compilations, etc.): *IUGG, Comptes Rendus of the General Assemblies, IUGG Chronicle* (6 times per annum); *IAG Bulletin Geodesique* (quarterly); *IAVCEI, Bulletin Volcanologique* (semi-annually); *IAHS, Bulletin des Sciences Hydrologiques* (quarterly); *IAGA News* (irregularly); *IAMAP News Bulletin* (irregularly); *IAPSO, Proces Verbaux* (2–4 years), *Publications Scientifiques* (irregularly).

INTERNATIONAL GEOGRAPHICAL UNION (IGU)

World Land Use Survey Commission

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The commission endeavours to further worldwide execution of land use surveys, within a general information system, as a tool for rational land use planning and management. Through its members, it investigates specific land use problems and prepares reports on the findings.

The *World Land Use Survey Series* is published by Geographical Publications Ltd., Berkhamsted, Herts., England in close co-operation with the commission.

Commission on Medical Geography

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The commission is concerned with the study of the geography of health, disease, and health sources. It investigates spatial relations as affected by the space-ecology of disease and the responses to it in varying patterns of health. It works mainly by liaison services, such as publication of the *Medical Geography Newsletter*, and through numerous seminars and symposia.

Working Group on the Dynamics of Shoreline Erosion

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AUSTRALIA

The working group is compiling a survey of the extent of advance or recession of the world's shorelines (with special references to sandy beaches) during the past century and relating the changes determined to shore processes.

It prepared a preliminary report on world shoreline changes for the IGU Congress (Moscow, 1976) and will thereafter proceed to completion of the survey, with detailed research on coastal sectors identified as of special scientific importance.

It intends to ask IGU to establish a Commission on the Coastal Environment for 1976–80 to complete the project on shoreline changes and to compile further data on:

(1) case histories of the impact of man's activities on the coastal environment;

(2) nature and location of sites of special scientific interest on the world's coasts;

(3) guidelines for environmental management in coastal regions.

Commission on Man and Environment

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The commission sponsors collaboration among geographers in comparative analysis of the environmental effects of technological development (Nelson and Scace 1974), the comparative analysis of social response to natural hazards (White 1974), the experience with establishment and management of natural preserves (Nelson, in press), man-environment theory, the mapping of environmental perturbations, the environmental impacts of growth on the urban fringe, evaluation of environmental effects of complex river development, and environmental constraints upon economic development.

Commission on Present Day Geomorphic Processes

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In its work with land forming processes, the commission has endeavoured to establish quantitative field experiments with comparable techniques to evaluate rates of geomorphic processes in various climatic and lithologic environments. It has concentrated its efforts on mountain, arid, and tropical processes. The commission has held four symposia in Canada (1972), West Germany (1973), Israel (1974), and Zaire (1975). (Alexandre 1976, Poser 1974, Schick et al. 1974, Slaymaker and McPherson 1972).

Commission on Geography in Education

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The commission is concerned with the various aspects of environmental education which can be treated in geography at school level with some reference to human settlement. Its goal is to produce teaching units suitable for secondary school use. It held regional meetings of experts on the teaching of geography in Southeast Asia and Oceania (Singapore, 1972), in Southeast Asia and the Southwest Pacific (Sydney, 1973), and in South and East Asia (Delhi, 1974).

Sydney workshop teaching units were reproduced by UNESCO in 1975; Delhi workshop units will be completed in 1977.

Commission on Agricultural Typology

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The commission is involved in a typological classification of agriculture on a world, national, and regional scale, which includes modelling of the various agricultural systems. Environmental problems generally are not emphasized except when interpreting the reasons why individual types of agriculture have developed in specific places. (Kostrowicki 1974, 1968, 1964; Kostrowicki and Tyszkiewicz 1970).

The commission was discontinued after 1976.

Working Group on Problems of Desertification in and around Arid Lands

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The working group collects evidence on the nature and causes of environmental changes contributing to the extension of deserts into marginal areas or an intensification of desert conditions within arid regions, including both man-made and natural changes. The Alice Springs, Australia, Field Conference (1974) was organized to deal with these problems. A conference report was subsequently submitted to UNESCO (Division of Ecological Sciences).

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For the most part the union and its commissions, committees, and affiliated organizations pursue basic scientific knowledge and practical applications to everyday problems in roughly equal measure. International collaboration under the aegis of the union promotes the sharing of ideas as well as data, and leads to the dissemination of the most advanced concepts. Harmonizing the results of research in one country with those of neighbouring countries yields a coherent picture of a whole region – even an entire continent – and raises the value of local increments to the geologic framework.

The union participates in all ICSU committees: SCOPE, SCAR, SCOR, COWAR, COSTED, CODATA, the Abstracting Board, and the Committee on Science Teaching.

The International Geological Correlation Programme is an unusual joint undertaking of IUGS (a non-governmental scientific union) and UNESCO (an intergovernmental body). IGCP is designed to promote international geologic research and to advance the application of geology in the developing countries. In many of these countries the best chance for promoting sound and orderly economic growth is through more effective use of resources of energy, minerals, and water.

The principal benefits of commission, committee, and association activities are the findings from the technical sessions and field conferences organized around the most significant problems in geology and in the most important field areas, the assembling of working groups for concerted attacks on special subjects, and the catalytic effect these have in focussing research on the main problems of the earth. The research results are published in standard serials of the geological sciences. The union itself publishes only the Quarterly Journal of IUGS, generally known as the *Geological Newsletter*. The Newsletter furnishes an up-to-date directory of all organizations affiliated with the union, a calendar of major geological meetings, agendas for many sessions, and summary accounts of meetings.

INTERNATIONAL UNION OF NUTRITIONAL SCIENCES (IUNS)

Professor B. Isaksson
Institute of Clinical Nutrition
University of Gothenberg
Sahlgren's Hospital
45 Gothenberg S–413
SWEDEN

The unbalanced diet and uneven distribution of nutrients comprise the primary problems that the union addresses in its scientific work. It is involved in scientific investigations of serious nutritional deficiencies, particularly in the developing countries. It promotes international co-operation in nutrition, encourages research, education, and training through its six commissions and thirty-two committees, and provides a means of communication with other appropriate organizations.

It collaborates closely with UNESCO and ICSU, of which it has been a member since 1968. Further, the union works with WHO, enjoys consultative status with FAO, UNICEF, and ECOSOC (Roster), and is an Associate member of CIOMS. The Union co-sponsors meetings organized by regional and other nutrition associations.

The *IUNS Newsletter* is published once or twice annually. The main objective of the Newsletter is to increase contact with the Adhering Bodies and to make the scientific activities of the IUNS better known among nutrition societies throughout the world.

Reports from the work of the Committees are available as IUNS publications.

The *IUNS Directory* comprises the statutes and rules of procedure; Adhering Bodies, Commissions, and Committees; permanent IUNS representatives in different organizations; and addresses of nutritionists involved in IUNS .

INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS (IUPAP)

Professor L. Kerwin
Secretary-General
Bureau du Recteur
Université Laval
Quebec, P.Q. G1K 7P4
CANADA

IUPAP co-operates with inter-union groups on problems of the environment and nominates experts to inter-union groups.

Under a proposal from the International Commission on Acoustics (ICA), SCOPE established a co-ordinating group to foster co-operative research on topics related to noise pollution. Professor A. Lara-Saenz was appointed Chairman of the group. Four working groups were organized as follows:

W.G. 1	Hearing Threshold Levels of Isolated Human Populations ICA Rep. – E. A. G. Shaw, Organizing Secretary – J. J. Knight
W.G. 2	Noise Propagation in the Atmospheric Boundary Layer ICA Rep. – J. Igarashi, Organizing Secretary – T. F. W. Emblenton
W.G. 3	Noise Propagation in Buildings ICA Rep. – A. Lara-Saenz, Organizing Secretary – G. Sacerdote
W.G. 4	Effects of Noise on Wildlife Communication ICA Reps. – I. J. Hirsch and J. Bosquet, Animator – J. L. Fletcher

They have undertaken a series of reports in preparation for the 1977 International Congress on Acoustics.

INTERNATIONAL UNION OF PHYSIOLOGICAL SCIENCES (IUPS)

Commission on Environmental Physiology

Dr. O. G. Edholm
Environmental Physiology Unit
University College
Gower Street
London WC1
UNITED KINGDOM

The commission organized meetings in Jerusalem (1975) and Indonesia (1975) and participated in organizing the International Congress of Physiological Sciences in Delhi (1975). Currently it is organizing a Satellite Symposium in Strasbourg in 1977.

Commission on Thermal Physiology

Dr. John Bligh
Institute of Animal Physiology
Babraham
Cambridge CB2 4AT
UNITED KINGDOM

The commission's activities have often related to environmental problems.

INTERNATIONAL UNION OF THEORETICAL AND APPLIED MECHANICS (IUTAM)

Professor F. I. Niordson
Secretary General
Technical University of Denmark
DK–28000 Lyngley, DENMARK

The union organizes several international symposia each year, many of which deal with basic processes in the environment. These include turbulent dispersion in the atmosphere and ocean, high-speed computer simulation of fluid dynamic phenomena, physical structure of shock waves, multi-phase flows, improvement in combustion efficiency, ground-water contamination, desalination, and noise pollution. Other IUTAM activities cover the statistical aspects of monitoring network design including optimization of time-space sampling grids, and the space-time response of measuring devices to fluctuating data; simulation modelling involving the representation of physical and biological processes by high-speed computing methods of fluid dynamics used for mathematical modelling of atmospheric and oceanographic phenomena; processes involving the magnitudes and rates of material flows in biogeochemical studies; and mathematical modelling of dispersion of pollutants involving their sources, transport, and magnitude of exposure in order to provide the information required in environmental toxicology and the planning of human settlements. (Bowden et al. 1967, Bretherton et al 1966, Davidson et al. 1969, Frenkiel 1962, Frenkiel and Munn 1974, Frenkiel and Sheppard 1959, Frenkiel and Stewartson 1969, Krautchenko and Sirieys 1966, Kuchemann 1956).

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH (SCAR)

Mr. G. E. Hemmen, Executive Secretary
SCAR Secretariat
Scott Polar Research Institute
Lensfield Road
Cambridge CB2 1ER
UNITED KINGDOM

Many SCAR activities are directed to understanding aspects of the Antarctic Environment. This includes the extensive continuing national programmes in biology, glaciology, geology, meteorology, geodesy, and cartography, human biology and medicine, solid earth geophysics, upper atmosphere physics, and oceanography. These activities are detailed in annual national reports to SCAR which also contain bibliographies of published scientific papers.

The SCAR system of permanent Working Groups or Groups of Specialists ensures that the national efforts in the different scientific fields are brought together and discussed, and that important problems for future investigation are identified. It also provides the framework for collaborative studies by two or more nations where such an approach is desirable.

In addition to the scientific Working Groups, SCAR has a permanent Working Group on Logistics, which provides a forum for interchange of national ideas on logistic support for scientific studies, and plans technical research on logistic problems.

From time to time on the recommendation of its appropriate subsidiary group, SCAR sponsors scientific symposia in collaboration with other relevant ICSU bodies. These have included: SCAR/WMO Symposium on Antarctic Meteorology, (Melbourne, 1959); Antarctic Symposium, (Buenos Aires, 1959); IASH/SCAR Symposium on Antarctic Glaciology, (Helsinki, 1960); SCAR Logistics Symposium (Boulder, 1962); SCAR/IUBS Symposium on Antarctic Biology, (Paris, 1962); SCAR/IUGS Symposium on Antarctic Geology, (Cape Town, 1962); SCAR/SCOR/IAPO/IUBS Symposium on Antarctic Oceanography, (Santiago, 1966); ICPM/WMO/SCAR Symposium on Polar Meteorology, (Geneva, 1966); SCAR/IUBS/SCIBP Symposium on Antarctic Ecology, (Cambridge, 1968); SCAR/IASH International Symposium on Antarctic Glaciological Exploration (ISAGE), (Hanover, 1968); SCAR/IUGS Symposium on Antarctic Geology and Solid Earth Geophysics, (Oslo, 1970); IAPSO/SCOR/IABO/CMG Congress 'The Ocean World' (SCAR half-day on 'Antarctic Ice and Water Masses'), (Tokyo, 1970); SCAR/ICPM/WMO Symposium 'Energy Fluxes over Polar Surfaces', (Moscow, 1971); Technical and Scientific Problems Affecting Antarctic Telecommunications, (Sandefjord, 1972); SCAR/IUBS/IUPS Human Biology and Medicine in the Antarctic, (Cambridge, 1972); SCOR/SCAR Polar Oceans Conference, (Montreal, 1974); SCAR/IUBS Antarctic Biology 'Adaptations within Antarctic Ecosystems,' (Washington, 1974).

Other activities of SCAR include the production and exchange through national committees of environmental impact statements relating to plans for new major scientific projects; a variety of projects that have relevance to climatic change which include activities of SCAR Working Groups on meteorology, Glaciology, geology, and the SCAR Group of Specialists on Late Cenozoic Studies; work on the possible impact on the environment of the Treaty Area and other ecosystems dependent on the Antarctic environment if mineral exploration and/or exploitation were to occur there; and formulation of proposals for and regular reviews of Specially Protected Areas and Sites of Special Scientific Interest. SCAR has been involved in this activity, in collaboration with the Antarctic Treaty Consultative meetings, since the early 1960's. The Group of Specialists on Living Resources of the Southern Ocean, jointly sponsored by SCOR, has been assigned the task of assessing the present state of knowledge of the Antarctic marine ecosystem and recommending research programmes to permit effective conservation, management, and utilization of the living resources of the region. The SCAR Group of Specialists on Seals has an advisory role to signatory governments under the 1972 Convention for the Conservation of Antarctic Seals.

Regular distribution of information on scientific programmes between SCAR nations, which enables specialists to be aware of all investigations being made in the Antarctic in their particular discipline, is achieved by individual contact and participation in scientific meetings, and through regular distribution by national committees of annual reports of their achievements and future plans.

SCAR Bulletin is published three times a year at the Scott Polar Research Institute, Cambridge and contains accounts of SCAR meetings, their resolutions and recommendations, accounts of Antarctic symposia, lists of names and addresses of SCAR members and Working Groups, annual lists of scientific stations and various papers of Antarctic interest. A Spanish translation of the *Bulletin* is published subsequently by the Instituto Antartico Argentino, Buenos Aires. (Adie 1964, 1970; Australian Academy of Science 1960; Carrick et al. 1964; Currie 1968; Deacon 1971; Edholm and Gunderson 1973; Gow et al. 1970; Holdgate 1970; National Academy of Sciences 1963; SCAR 1972; Sheffield 1972; WMO 1967, 1973; van Zinderen Bakker 1969, 1973).

SPECIAL COMMITTEE ON THE INTERNATIONAL BIOLOGICAL PROGRAMME (SCIBP)

Dr. E. B. Worthington
c/o Linnean Society
Burlington House
Piccadilly
London W1V 0LQ
UNITED KINGDOM

SCIBP was responsible for organizing world programmes on biological productivity and human welfare for the decade from 1964 to 1974. The programme is now at an end, and the Scientific Committee has been disbanded. The publication stage of IBP is still progressing and 30 volumes of international syntheses have been published so far. These provide a solid basis of reference for SCOPE's continuing biological activities.

SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH (SCOR)

Mr. R. I. Currie
Secretary
Dunstaffnage Marine Research Laboratory
P.O. Box 3
Oban, Argyll PA34 4AD
UNITED KINGDOM

The committee is concerned primarily with basic scientific problems which affect the environment of the sea. SCOR projects with particular interest in advancing the understanding of the environment and the effects of human activity upon it are studies dealing with paleo-oceanography, pollution of the Baltic, river inputs to ocean systems, influence of the ocean on climate, and other research projects related to the ocean environment. Activities of a number of SCOR Working

Groups have some relevance to the broad problem of ocean-atmosphere interaction.

SCOR is an official scientific advisory body to the Intergovernmental Oceanographic Commission and to the UNESCO Division of Marine Sciences. Reports of SCOR Working Groups are sometimes published in *SCOR Proceedings*, an eight page monthly publication which constitutes the record of SCOR achievements, sometimes as numbers in the series *UNESCO Technical Papers in Marine Science* and sometimes as *UNESCO Monographs on Oceanographic Methodology*. Its work with intercalibration and standardization of measurements and data, and international oceanographic tables which are published by UNESCO, is especially useful to environmental science.

SCOR Working Groups

WG 10 – Oceanographic Tables and Standards

Chairman: Professor K. Grasshoff

Terms of Reference: To carry out all the necessary preparatory work for publishing new oceanographic tables; to advise on the certification of the standard sea water; to advise on such further investigations as may be desirable.

WG 34 – Internal Dynamics of the Ocean

Chairman: Professor A. Robinson, USA

Terms of Reference: To identify the critical scientific problems of the internal dynamics of the ocean and to suggest the most appropriate ways to study them; to advise on the design of mid-ocean dynamics experiments.

WG 36 – Coastal and Equatorial Upwelling Processes

Chairman: Dr. K. N. Fedorov, USSR

Terms of Reference: To review present knowledge of the physical, chemical, and biological processes involved in coastal and equatorial upwelling; to evaluate strategies for the investigation of these processes and recommend appropriate investigations; to examine the application of these recommendations in the upwelling region of Northwest Africa.

WG 38 – Ocean Processes in the Antarctic

Chairman: Dr. T. Kvinge, Norway

Terms of Reference: To recommend observational and theoretical studies to facilitate the design of a major study of the circulation of the Antarctic ocean. The group will take into account the findings of WGs 34 and 38 and integrate their recommendation with the plans of WG 47.

WG 40 – Paleo-oceanography

Professor T. van Ardel
School of Oceanography
State University
Corvallis, Oregon 93771
USA

WG 42 – Baltic Pollution

Dr. G. Kullenberg
Institut for Fysisk Oceanografi
Haraldsgade 6
2200 Copenhagen N
DENMARK

WG 46 – River Inputs to Ocean Systems

Professor D. Lal
Physical Research Laboratory
Navrangpure, Ahmedabad 38009
INDIA

WG 47 – Oceanographic Programmes During FGGE

Chairman: Professor H. Stommel, USA

Terms of Reference: To develop plans for comprehensive oceanographic programmes associated with FGEE and to assist other appropriate international and national bodies in the implementing of such programmes.

WG 48 – Influence of Ocean on Climate

Professor H. Charnock
Institute of Oceanographic Sciences
Wormley, Godalming, Surrey
UNITED KINGDOM

WG 49 – Mathematical Modelling of Oceanic Processes

Chairman: Dr. K. Bryan, USA

Terms of Reference: To review the findings of other SCOR working groups as they relate to the mathematical modelling of oceanic processes, and to advise on the objectives and design of relevant numerical models.

WG 50 – Biological Effects of Ocean Variability

Chairman: Dr. A. R. Longhurst, UK

Terms of Reference: To review data from biological monitoring programmes and relate those to ocean climatological data from the same regions and periods, to consider the synthesis of such data and the hypotheses that could be erected to account for the observed interactions, and to assist in the organization of a Special Symposium for the JOA in which selected case studies of the interactions between environmental changes and those in the distribution and abundance of fish stocks or other organisms could be presented.

WG 54 – Living Resources of the Southern Ocean

Chairman: S. Z. El-Sayed, USA

Terms of Reference: To assess the present state of knowledge of the Antarctic marine ecosystem from the point of view of structure, dynamic functions, and biomass of the organisms at different trophic levels; to encourage and stimulate investigations of the ecology and population dynamics of the organisms at different trophic levels with particular reference to krill, squid, fishes, and whales; to maintain liaison with FAO; to advise SCAR and SCOR and through them, other international organizations and in particular to respond to relevant recommendations, conveyed to the group by SCAR or SCOR of IOC and the Antarctic Treaty Consultative Meetings.

WG 55 – Prediction of 'El Niño'

Membership to be established.

Terms of Reference: To examine possible prediction schemes and indices for 'El Niño' and to recommend the research needed to define the processes that should be taken into account in such forecasting procedures.

COMMITTEE ON SPACE RESEARCH (COSPAR)

Working Group 6 (WG 6)

Dr. M. Tepper
Director
Meteorology, Code ERD
NASA
Washington, D.C. 20546 USA

The Working Group is concerned with application of space-based technology to problems of the earth and its atmosphere. This includes providing the Scientific Committee on Antarctic Research with a detailed review of space possibilities related to research and operational problems in the Antarctic, and providing the United Nations with information on cost effectiveness of space-based observations for earth surveys.

The *panel on Meteorology and Climate* studies the feasibility of space-based observing systems to provide global meteorological observations for numerical experimentation on the limit of atmospheric predictability; evaluates space-based observing systems that could be implemented to address observational needs of basic climate studies; and applies space technology to observations needed for environmental studies. The panel contributed to the development of the Global Atmospheric Research Programme (GARP). It has organized numerous symposia on space-based systems for meteorology including a comprehensive symposium (Philadelphia, 1976) with COSPAR, WMO, JOC, IUGG/IAMP, AMS on 'Meteorological Observations from Satellites: Their Contribution to the FGGG.'

The *panel on Earth resources and Environment* conducts informal discussions of the status of activity in various countries related to using remote sensing techniques in studies of resource management and environmental problems. It organized a symposium (Konstanz, 1973) on 'Approaches to Earth Survey Problems through the Use of Space Techniques'; and a workshop (San Jose dos Compos, Brazil, 1974) on remote sensing techniques for earth resource problems in Latin America, Asia, and Africa. It is organizing with WMO and FAO a symposium for its 1977 annual meeting on 'Satellite Contributions to Food Information Systems' and producing manuals on space-based techniques for earth resource studies for use in developing countries. It prepared a document for SCOPE indicating the feasibility of monitoring factors identified as important in studies of the environment by space techniques.

The *panel on Stratospheric and Mesospheric Meteorology* co-ordinates rocket launchings to study specific features of the stratosphere and mesosphere. It served as a forum for discussion of results of stratospheric circulation problems, photochemical equilibrium of the ozone layer, and dynamics of sudden stratospheric warmings in early winter at high latitudes; and organized discussions of results from the WMO-sponsored rocket intercomparison campaigns.

The *Ad Hoc Panel on Monitoring Pollution from Space* investigates space-based possibilities for the detection and monitoring of a variety of pollutants important to life processes and the quality of the environment.

A joint COSPAR/IAMAP (IUGG) *Ad Hoc Working Group on Calibration and Intercomparison of Rocket and Satellite Radiation Instruments* is working to achieve standardized calibration procedures; and organized a symposium on the problems of calibration and intercomparison at the IUGG General Assembly (Grenoble, 1975).

Papers presented at all working sessions will be published together in an issue of the *Journal of the Optical Society of America.*

Arbeitsgruppe Biophysikalische Raumforschung

Professor Dr. H. Bucker
Arbeitsgruppe Biophysikalische Raumforschung
6000 Frankfurt Main 70
Kennedy Allee 97
FEDERAL REPUBLIC OF GERMANY

The working group is concerned with possibilities for survival of terrestrial organisms in space or on other planets, with possible deleterious effects of space or planetary atmospheres on terrestrial organisms, and with biological indicators sensitive to toxic agents. It works to establish effective planetary quarantine requirements, ascertain hazards to astronauts during space flights, and estimate the probability of existence of extraterrestrial life.

(Bock 1974; Buecker et al. 1976, 1974, 1972, 1971, 1970; Buecker and Horneck 1975, 1970, 1969a, 1969b; Frankenberg-Schwager et al. 1975; Horneck et al. 1971; Horneck and Buecker, 1971; de Mendonca 1974; Taylor et al. 1974.)

COMMITTEE ON SCIENCE AND TECHNOLOGY IN DEVELOPING COUNTRIES (COSTED)

Dr. S. Ramakrishna
Secretary, COSTED
Indian Institute of Science
Bangalore 560012
INDIA

The Committee's goal is to foster the growth of science and technology in the developing countries. It co-ordinates and encourages efforts by the International Scientific Unions to assist the developing countries; works with the special and scientific committees of ICSU in order to facilitate the greatest possible participation in their programmes by scientists of the developing countries; fosters affiliations with COSTED of national or regional committees which could identify scientific and technical problems related to development and recommend programmes and other activities for COSTED; provides liaison and advisory services, when requested, to international and regional scientific development organizations such as the specialized agencies of the UN and the non-governmental organizations active in this field; and considers the methodology of using science and technology to assist the developing countries.

COSTED has responded to specific requests from national scientific organizations of several developing countries by arranging missions to these countries. It has also endeavoured to identify the problems of developing countries and see how the ICSU Unions, Committees, and National Organisations could best help in solving them (Role of Science and Technology in Developing Countries 1971).

COSTED recognizes the vital role which science teaching has to play in the developing countries and has embarked on a programme of meetings for studying, in depth, the role of science teaching. It has evolved a programme whereby the problems of natural resources and the environment can be linked with the problem of science teaching and an integrated programme undertaken (Science Education in Developing Countries 1973).

Recognizing the need for providing support for young scientists to attend scientific meetings, COSTED awards travel fellowships to young scientists from developing countries.

A COSTED Newsletter, to be issued four times every year, began in 1976.

COSTED has organized a series of meetings to study the impact of the utilization of natural resources on the welfare of the developing countries. The first meeting of the series entitled 'Resources and the Environment – the Role or Science Education' was held in Aura, Ghana in January 1975, with special emphasis on soil and water. The second meeting, co-sponsored by CTS, IUGG, and SCOPE was held in Kuala Lumpur, Malaysia in April 1976, with special emphasis on minerals.

SPECIAL COMMITTEE ON SOLAR-TERRESTRIAL PHYSICS (SCOSTEP)

Dr. E. R. Dyer, Jr.
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418 USA

The committee promotes the study of correlations between solar-terrestrial physical phenomena and meteorological-climatological patterns.

It is undertaking the Middle Atmospheric Programme (MAP), endorsed by COSPAR, IUGG, IAGA, and IAMAP. MAP will consider the structure, energetics, dynamics, and compositions of the regions from the tropopause to the top of the mesosphere (100 km). It will be a worldwide programme of co-ordinated observations using all available techniques. It is intended that MAP will continue into the 1980's.

The International Magnetospheric Study (IMS) will deal with the magnetosphere solar wind, interplanetary magnetic fields, energetic particles, solar flares, and geomagnetic substorms. IMS is scheduled for 1976–78, but undoubtedly will be extended.

Another programme, Monitoring the Sun–Earth Environment (MONSEE) is a service-oriented programme to collect, store, and disseminate solar-terrestrial physics data. Data collection is handled through the WDC (Allen 1976; Dyer 1974, 1975, 1976 (continuing); Shapley et al. 1975; Shea 1975 (continuing)).

SCIENTIFIC COMMITTEE ON WATER RESEARCH (COWAR)

Dr. E. B. Worthington
c/o Linnean Society
Burlington House, Piccadilly
London W1V 0LQ
UNITED KINGDOM

This committee has been involved in extensive study of man-made lakes. A large interdisciplinary international symposium was held (Knoxville, 1971). A register of large man-made lakes around the world is being compiled. A register of small man-made lakes, which are calculated to have a total environmental effect even greater than the large lakes, will follow.

Arid land irrigation is another major activity of the Committee. An international interdisciplinary symposium (Alexandria, 1976) brought together physical, biological, chemical, medical, and social information. A joint working group (SCOPE, COWAR, UNESCO, etc.) prepared an analysis of arid land irrigation studies after the symposium.

COWAR is also involved actively in studies on water weeds and their effects on water flow, water control, irrigation, and long-term changes in water quality, in close association with the International Hydrological Programme of UNESCO.

The future of water research within ICSU is under study by a small Ad Hoc Committee whose report is expected during 1976. (Ackermann et al. 1973, SCOPE 1972).

GLOBAL ATMOSPHERIC RESEARCH PROGRAMME (GARP)

Professor B. Doos
c/o World Meteorological Organisation
Case Postale No. 5
1211 Geneva 20
SWITZERLAND

Jointly organized by the International Council of Scientific Unions and the World Meteorological Organisation, GARP was established in 1967 to study the physical processes of the atmosphere that are essential for the understanding of the large-scale fluctuations which control changes of the weather, and for a better understanding of the physical basis of climate. Its establishment recognizes the fact that scientific and technological developments in meteorology and related fields present an unprecedented opportunity for advancing man's knowledge of atmospheric processes and for applying such knowledge for practical purposes.

The work is structured into sub-programmes, the central one of which is the Global Sub-programme, with the objective of obtaining a global data set adequate to provide initial and verifying data for global models of atmospheric behaviour. The principal effort in this sub-programme is the First GARP Global Experiment (1977–1979) – an international effort of data gathering and analysis unprecedented in scope. The first major experiment to be completed in the series, the GARP Atlantic Tropical Experiment, was successfully carried out in 1974.

GARP is predicated on the assumption that numerical models provide an indispensable tool, and the Numerical Experimentation Sub-programme not only attempts to lead to the improvement of models but gives guidance for the planning of observations.

Other sub-programmes have as principal objectives the determination of improved techniques for parameterizing physical processes too small in scale to be defined by global numerical models or realistic observing networks. These include the Tropical, Polar, Monsoon, Climate Dynamics, Radiation, and Air-Surface Interaction Sub-programmes.

GARP issues a number of publications based on its research activities. These are the *GARP Publications Series*, the *GARP Special Report Series*, the *GATE Reports*, and the *GARP Newsletter*

COMMITTEE ON TEACHING SCIENCE (CTS)

Mr. D. G. Chisman
Secretary
British Council
10 Spring Gardens
London SW1
UNITED KINGDOM

The committee includes in its programme a study of the relevance of science education, particularly integrated science, to environmental problems. It assists in the development and improvement of science education at all levels, co-ordinates the activities of the teaching committees of the individual scientific unions, and initiates activities in multidisciplinary aspects of science education.

CTS sponsors jointly with COSTED and SCOPE regional seminars (Ghana, 1975; Kuala Lumpur, Malaysia, 1976) at university level on the study of the environment and natural resources and the design of science courses relevant to the understanding and possible solution of some of their related problems.

With UNESCO support, CTS established an International Council of Associations for Science Education (ICASE), which has separate officers and executive committee. Within two years of its foundation in 1973, ICASE had 28 member associations and was developing its own programme of activities, including publications for science teachers, a newsletter, a directory and guide to science teachers' associations and the organization of regional seminars for science teachers.

FEDERATION DES SERVICES PERMANENTS D'ASTRONOMIE ET DE GEOPHYSIQUE (FAGS)

Dr. G. A. Wilkins
Secretary
Royal Greenwich Observatory
Herstmonceux Castle
Hailsham, Sussex 0N27 1RP
UNITED KINGDOM

The federation of Astronomical and Geophysical Services consists of the following Permanent Services, each of which is engaged on the compilation, evaluation, and analysis of data from observing stations that are distributed widely around the world.

1895	International Polar Motion Service	Mizusawa, Japan
1911	Bureau International de l'Heure	Paris, France
1928	Quarterly Bulletin on Solar Activity	Zurich, Switzerland
1932	Permanent Service for Geomagnetic Indices	De Bilt, Netherlands
1933	Permanent Service for Mean Sea Level	Bidston, England
1953	Bureau Gravimetrique International	Paris, France
1960	International Centre for Earth Tides	Brussels, Belgium
1961	Scientific Ballooning and Radiation Monitoring Organisation	St. Maur, France
1962	International Ursigram and World Days Service	Meudon, France
1967	Permanent Service on the Fluctuations of Glaciers	Zurich, Switzerland

The date is that of the formation of the Service or of its predecessor in the same field; the title indicates the field of activity of the Service; the place is the present location of the Service.

Each Service works under the scientific direction of a Directing Board, which is appointed by one or more of the scientific unions, IAU, IUGG, and URSI. The Board determines the type of data to be collected, the methods of reduction and analysis to be used, and the format of the publication for the results. The Federation is guided for administrative and financial purposes by a Council composed of representatives of the three Unions and of ICSU. Grants, totalling about $50,000 per year, are made to FAGS by ICSU and UNESCO; the Council allocates these funds to the Services in accordance with the general policy of the Unions. Most of the costs of the individual Services and all of the costs of data acquisition are borne by the host institutions and the observing stations. The international funds are used primarily to meet the special expenses involved in reducing and publishing the data to meet the requirements of the international scientific community.

The Services in FAGS are direcly concerned with the time-varying characteristics of the Earth–Sun environment. In these areas of study, small but significant trends and periodic changes become evident only after the careful statistical examination of long sequences of observations. Their detection and correlation help scientists to understand the processes that control or influence such important phenomena as the weather and climate, radio communications, earthquakes, and changes in sea level. The improvement of our capabilities for observation and computation makes it vital that these sequences of observation of environmental indicators be continued and that the data be made available for general use in convenient forms.

PANEL ON WORLD DATA CENTRES (WDC's)

Dr. E. R. Dyer, Jr.
National Academy of Sciences
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Washington, D.C. 20418
USA

The system of World Data Centres was established for the International Geophysical Year, 1957–1958 and has continued with only minor changes to serve the solar-geophysical community.

The thirty-odd branches of the WDC system are grouped into two 'universal centres' (that is, those that maintain a complete collection of all kinds of data), namely, WDC–A in the the USA and WDC–B in the USSR; other branches scattered through Western and Central Europe, Japan, and India are collectively known as WDC–C. The WDC–C Centres are actually independent centres dealing mainly in data from only one or a small number of disciplines.

The WDC system collects and archives data in the following fields: solar-terrestrial physics (solar, interplanetary, and ionospheric phenomena; the variable component of the geomagnetic field; auroras, airglow, and cosmic rays); space research; oceanography; glaciology; solid-earth geophysics (seismology, tsunamis, marine geology and geophysics, gravimetry, earth tides, recent movements of the earth's crust, rotation of the earth, the stationary or slowly changing component of the geomagnetic field, and paleo- and archeomagnetism; volcanology and geothermic will be added); and meteorology (Dyer 1973).

Annual directories of recent guides and/or supplements to the *Consolidated Guide* are planned until it becomes too obsolete to use, at which time a new revised 'Fourth Consolidated Guide' will be published. No annual updates have been published yet.

PACIFIC SCIENCE ASSOCIATION (PSA)

Pacific Science Association
Box 6037
Honolulu, Hawaii 96818
USA

The association is devoted to the study of the scientific problems of the Pacific region. It has identified five scientific areas of critical concern wherein it concentrates its research efforts.

Mineral Resources: the extreme importance of mineral resources in the Pacific, in light of current and anticipated world demand and of the welfare of Pacific island peoples and environments, requires generation and development of new research.

The Social and Professional Conditions of Scientific Work in Rapidly Developing Countries: in light of the numerous problems affecting Pacific peoples and their environment under the particular stresses of rapid change (social, technological, economic, political, and physical). Matters needing immediate attention are the training of indigenous personnel, the development of appropriate manpower infrastructures, the according of equitable professional prestige, the protection of traditional lifestyles and traditions, and the preservation of natural features.

Ecology and the Rational Management of Island Ecosystems: the aims of the Man and Biosphere (MAB) Project 7 programme and the objectives of the association are viewed as coincident in this area, and there is a need for liaison with the sponsoring body, participating governments, and the natural and social scientists engaged in this broad co-operative endeavour.

Conservation of Natural Areas and of the Genetic Material they contain: the establishment of so-called biosphere reserves is of exceptional value in the Pacific where so many natural areas and their components have suffered degradation as a result of development, the introduction of alien species, and the absence of information and controls. This is an area of mutual interest to the PSA and MAB Project 8.

The Ecological Impact of Human Activities and Conflicts in Resource Allocation in Coastal Zones: the greater proportion of the population of the Pacific is concentrated in coastal areas and is dependent upon coastal waters and marginal wetlands for a wide variety of resources. Great demands have been placed upon these resources and yet the study of this vital land-sea interface has been neglected. MAB project 5E works closely with PSA in this area (Force and Bishop 1975).

Inter-congresses of PSA are held at four-year intervals. The theme of 'Appropriate Technology' has been chosen for the third Inter-congress to be held in Bali, Indonesia in July, 1977. Scientific committees of interest to SCOPE are the following:

Freshwater Sciences – Professor Syuiti Mori, Otsu Hydrobiological Station, Kyoto University, Otsu, Shiga-Ken, 520–01, Japan

Geography – Dr. R. G. Ward, Dept. of Human Geography, Australian National University, Canberra

Marine Sciences – Dr. V. I. Ilichev, Institute of Oceanology, Academy of Sciences of the USSR, Vladivostok, USSR

Pacific Islands Ecosystems (Mandate of this Committee to be considered by the Pacific Science Council during the Third Inter-congress, July 1977)

Scientific Study of Coral Reefs – Dr. R. T. Tsuda, Marine Laboratory, The University of Guam, P.O. Box EK, Agana, Guam 96910, USA

Solid Earth Sciences – Dr. N. A. Shilo, Northeast USSR Scientific Research Institute, Magadan, USSR

INTERNATIONAL UNION FOR QUATERNARY RESEARCH (INQUA)

Professor Dr. R. Paepe
Secretary Treasurer
Vrije Universiteit Brussel
Geografisch Instituut
A. Buyllaan 87
B–1050 Brussels, BELGIUM

In its efforts to advance understanding of the Quaternary environment, the INQUA studies Quaternary deposits with regard to economic value and engineering considerations, and hopes to publish a worldwide series of maps of Quaternary deposits.

It advocates establishing working groups of scientists from developing nations with personnel and material support from developed countries to study environmental problems. INQUA seeks to support local scientists in their investigations of environmental problems by organization of scientific meetings.

Environment meetings were held in Uppsala and Brazil in 1975.

INTERNATIONAL SOCIETY OF SOIL SCIENCE (ISSS)

Dr. R. Dudal
Secretary-General
FAO
V[illegible]elle Terme de Caracalla
00153 Roma, ITALIA

The society seeks to improve the scientific basis for management of land resources, specifically: international assessment of available land resources, global assessment of land degradation hazards, and planning for effective land use.

In working toward these objectives, ISSS collaborates with UNESCO, FAO, UNEP, and UNDP. The global assessment of land degradation, which is carried out by FAO in co-operation with UNEP, UNESCO, and ISSS, will be completed in its first phase by the end of 1978. The publication of the FAO/UNESCO Soil Map of the World is in an advanced stage of completion (FAO 1965 and continuing).

INTERNATIONAL ASSOCIATION ON WATER POLLUTION RESEARCH (IAWPR)

Dr. G. J. Stander
President
P.O. Box 824
Pretoria 0001
REPUBLIC OF SOUTH AFRICA

The association deals with all aspects of water pollution control in surface, underground, and marine waters. It holds biennial conferences on water pollution abatement (Sydney 1976); and holds more specialized conferences on designated problems. (*Water Research*; Eckenfelder and Cecil 1972; Jenkins 1973, Jenkins and Ives 1973).

APPENDIX C

*Steering Committee and Project Chairmen in the SCOPE Mid-term Programme**

Ian Burton, Gordon C. Butler, Erik Eriksson, Francois N. Frenkiel, Gordon T. Goodman, Martin W. Holdgate, Akin L. Mabogunje, N. N. Moiseev, J. Parizek (until December 1975), Ralph O. Slatyer, Gilbert F. White; *Ex officio* – Victor A. Kovda, Mohamed Kassas, Thomas F. Malone; *Staff* – William Robertson IV, Melinda L. Cain, Victoria L. Jones.

I. BIOGEOCHEMICAL CYCLES

Chairmen:

Victor A. Kovda, Faculty of Pedology, Moscow State University, Moscow V-234, USSR *and*

J.W.M. la Riviere, International Courses in Hydraulic and Sanitary Engineering, Oude Delft 95, Delft, The Netherlands

II. RENEWABLE NATURAL RESOURCES

Chairmen:

R. O. Slatyer, Dept. of Environmental Biology Research, School of Biological Sciences, Australian National University, P.O. Box 475, Canberra City, A.C.T., Australia, *and*

G. F. White, Inst. of Behavioral Science, University of Colorado, Boulder, Colorado, USA

III. HUMAN SETTLEMENTS

Chairman:

A. L. Mabogunje, Dept. of Geography, University of Ibadan, Ibadan, Nigeria

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*The participation of USA scientists in the Steering Committee and in the preparation of this report was made possible by a grant from the Andrew W. Mellon Foundation.

IV. ECOTOXICOLOGY

Chairman:

G. C. Butler, Div. of Biology, National Research Council, Ottawa K1AOR6, Canada

V. SIMULATION MODELLING

Co-chairmen:

F. N. Frenkiel, Computation and Mathematics Dept., Naval Ship Research and Development Centre, Bethesda, Md., USA

D. W. Goodall, CSIRO Div. of Land Resources Management, Canberra, Australia

VI. MONITORING

Chairman:

G. T. Goodman, MARC, Chelsea College, the Octagon Building, 459A Fulham Road, London SW10 0QX, UK

VII. COMMUNICATION AND SOCIETAL RESPONSE

Chairman:

I. Burton, Inst. for Environmental Studies, University of Toronto, Toronto M5S 1A4, Canada

Note

Participants in preparatory groups, working groups and symposia are listed in the SCOPE reports on these activities.

APPENDIX D

Methyl Mercury: Critical Groups and Sources of Intake

(Report from an Expert Group, 1971)

When 'mercury' is released into the environment it may appear as, or be converted into, any of the following chemical forms:

metallic mercury (Hg)
inorganic mercury (Hg^{+} and Hg^{++})
monomethyl mercury ($CH_3 - Hg^{+}$)
dimethyl mercury ($CH_3 - Hg - CH_3$)

The 'methyl mercury' discussed in this appendix is monomethyl mercury ($CH_3 - Hg^{+}$)

1. Man

(a) Adult

(i) Occupational exposure
- lab personnel
- industrial workers and farmers handling seed dressings
- workers in pulpmills and sawmills

(ii) Non-occupational exposure
- persons consuming foodstuffs with high methyl mercury levels: dressed seed, game birds, seabird eggs, fish and shellfish, meat

(b) Foetus
Placental transfer and foetal concentration (Kojima and Fufita 1973)

2. Domestic Animals

(a) Cats (Takizawa et al. 1971), from eating contaminated fish and wild birds

(b) Pigs, from eating contaminated grain (Pierce et al. 1972)

3. Wildlife

(a) Fish, living in waters above sediments contaminated with inorganic mercury

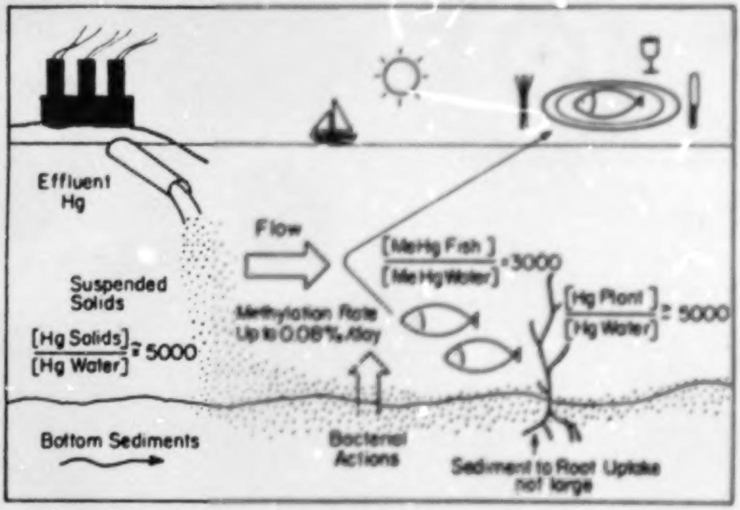
Effluent Hg
Flow
[MeHg Fish] / [MeHg Water] = 3000
Suspended Solids
[Hg Plant] / [Hg Water] ≥ 5000
Methylation Rate Up to 0.08%/day
[Hg Solids] / [Hg Water] ≥ 5000
Bottom Sediments
Bacterial Actions
Sediment to Root Uptake not large

Figure 17 Aquatic food chain for mercury and methyl mercury

(b) Birds (Report from an Expert Group 1971, Borg et al. 1969)

- (i) Seed-eating birds (dressed grain)
- (ii) Fish-eating birds (contaminated fish)
- (iii) Predatory birds (secondary intoxication from contaminated fish or birds)

(c) Mammals, both terrestrial and aquatic, with a fish diet

4. Plants

(a) Phytoplankton (Peakall and Lovett 1972)

(b) Higher plants (Mortimer and Kudo 1975)

ENVIRONMENTAL TRANSPORT

This summary on methyl mercury will not deal with the biogeochemical transport of all forms of mercury in the environment but will concentrate on the critical food chains to man and wild birds.

For seed-eating birds no model is needed since, if one knows the concentration of the organic mercury in the seeds, one can calculate the uptake [f1 = 0.9 (approx.)] and the resulting body and tissue contents (see METABOLISM section and the sub-sections General and Wild birds). This route can be monitored by analyses of feathers.

For man and fish-eating birds the most important environmental route is through contaminated fish and other edible aquatic organisms. In this route it is necessary to consider the occurrence and transport of mercury in inorganic form as well as methyl mercury since methylation of mercury is known to occur in aquatic ecosystems (Wood 1974).

In an aquatic system almost all the mercury is present in the sediments, in inorganic form. The partition coefficient for inorganic mercury between sediment and water (w/w) ranges from 1,000 for coarse sand to 5,000–50,000 for organic sediments (Ottawa River Project 1976). From this inorganic mercury in the sediments, which is retained with a half-time of 1–5 years depending on hydrological conditions, methyl mercury is continuously produced, probably by bacterial action (Wood 1974), at a rate which has been estimated (Langley 1973) at 15°C in the laboratory as 1–5 [mean = 2 (approx.)] micrograms per square meter of sediment per day. It is difficult to correlate this rate precisely with the mercury content of the sediment since the rate of net production of methyl mercury results from two or three reaction steps, some of which may be reversible (Wood 1974). For example, high concentrations of methyl mercury in the sediment may lead to some conversion back to inorganic mercury or to further methylation to the less toxic dimethyl mercury.

After release into the body of water above the sediment the methyl mercury is taken up by fish, both directly through the gills and in methyl mercury-containing food. If one knows the concentration of methyl mercury in the water one can calculate the rates of uptake by fish and the body and muscle contents at any time after the beginning of uptake (see **METABOLISM** section, Fish sub-section).

The proportion of total mercury in the form of methyl mercury will be magnified at each trophic level due to the more efficient uptake of methyl mercury to the blood (f1 for methyl mercury = 0.95 and f1 for inorganic mercury = 0.15) and due to the longer biological half-life of methyl mercury. For example, for the uptake from food, if F = the fraction of total mercury in the form of methyl mercury in the food, the proportion in the eater of that food

$$F_a = \frac{0.95}{0.80 + \frac{0.15}{F}} \quad \text{(see p. 212 for derivation)} \qquad \text{(E1)}$$

Thus, if invertebrates have $F = 0.3$ (found in field observations), the fish that eat them will have

$$F_a = \frac{0.95}{0.80 + \frac{0.15}{0.3}} = 0.73$$

and the fish b that eat fish a will have

$$F_b = \frac{0.95}{0.80 + \frac{0.15}{0.73}} = 0.95$$

and so on. Similar magnification factors of the proportion of mercury in the form of methyl mercury can be demonstrated for uptake by gills. These values are consistent with those found in the field and no further methylation during passage up the food chain is required to explain the increasing fractions of mercury as methyl mercury. In fact, there was an early demonstration that the analysis of fish muscle for methyl mercury could be used to estimate the level of mercury present in the water environment (Johnels et al. 1967).

Westermark and Johnels (1975) have formulated the magnification of methyl mercury concentrations in birds as a function of the biological half-lives in predator and prey. Our derivation of a comparable formula shows the magnification factor for a single stage to be

$$\frac{a_n}{x_n}\cdot F_n$$

where

a_n = g of prey $n-1$ eaten per day per g of predator n
x_n = fractional rate of loss (d^{-1}) of methyl mercury from n
F_n = fraction of the methyl mercury eaten by n absorbed to blood

Thus for a food chain of n levels the total magnification

$$=\frac{a_1}{x_1}\cdot F_1 x\frac{a_2}{x_2}\cdot F_2 x\ldots\frac{a_n}{x_n}\cdot F_n x b \qquad \text{(E2)}$$

where b = the concentration of methyl mercury in the first level (g/g).

METABOLISM

1. General

Methyl mercury is taken up through the intestines and the lungs of terrestrial animals and the intestines and gills of fish. It is also absorbed through the skin but quantitative data are lacking.

For a constant rate of uptake, I, the equation describing body content as a function of time is (Butler 1972, Nordberg et al. 1973)

$$q(t)=I\int_0^t R_s(u)\,du \quad \text{(see p. 213 for explanation)} \qquad \text{(E3)}$$

where

$q(t)$ = the body content at time t, μg
I = the rate of uptake to blood, μg/day
$R_s(u)$ = the retention equation
= the fraction retained on day u following a single uptake

At times soon after uptake, the blood and kidneys show concentrations 10–20 times higher than the body average but at later times these decline relatively. In fish the concentration in muscle is not greatly different from that in whole body but since skeletal muscle constitutes about half the mass of the total body, muscle is the principal storage tissue.

Since brain and nervous tissue seem to be the critical organ in mammals the deposition in these tissues is of special interest. In mouse, cat, dog, pig, and monkey the concentration of methyl mercury in the brain varies from 0.5–5 times that in blood. The rat appears exceptional in that the corresponding ratio is about 0.1.

Methyl mercury is taken up to the blood to a greater extent than inorganic mercury and methyl mercury has a much longer biological half-time in both terrestrial animals and fish than has inorganic mercury. When mercury is released to the environment a small fraction is converted to methyl mercury; so animals exposed to mercury in the environment assimilate both inorganic and methyl mercury (the latter to a greater extent). The result of the metabolic behaviour described above is that there is a preferential accumulation of methyl mercury to relatively high levels. Calculations on this topic were presented in preceding paragraphs.

Most of the methyl mercury taken up by man is excreted in the faeces. The minor fraction (as low as one-tenth) excreted in the urine also varies with time after uptake. For these reasons urinary analyses are of doubtful value for calculating body content and this has been confirmed by surveys on industrial workers contaminated internally with mercury compounds (Ladd et al. 1963) and on the farmers of Iraq who ate wheat contaminated with methyl mercury (Bakir et al. 1973).

2. Terrestrial Animals

a. Ingestion

For all animals including man, f1, the fraction taken up from the gastrointestinal tract, is 0.9–0.95 for both aqueous solutions and food.

b. Inhalation

In the Lung Model of ICRP (Bates et al. 1966) methyl mercury would be a class D compound and therefore 60% of the amount inhaled would be rapidly taken up to blood.

c. Tissue Distribution and Retention

(i) Man

The following metabolic information is given to relate diagnostic measurements on humans to the methyl mercury levels in the food they eat.

In man eating methyl mercury-contaminated fish the equilibrium levels in blood were described by the relation (Miettinen et al. 1971):

$$Y = 0.8X$$

where

Y = concentration in blood (ng/g)

X = amount ingested in fish (μg/day)

Studies of the epidemic of methyl mercury poisoning in Iraq as a result of eating contaminated wheat (Bakir et al. 1973) yielded the following results:

The blood concentration could be described by the relation

$Y = 16X$ for patients > 10–15 years old

$Y = 10X$ for patients > 18 years old

where

Y = blood concentration (ng/ml)

X = total intake (mg) during 40–60 days

$Cib = Cmb$ for infants nursed by methyl mercury-contaminated mothers

where

Cib = concentration in infant blood

Cmb = concentration in mother's blood

$Cmm = 0.03\ Cmb$

where

Cmm = concentration in mother's milk

Since the concentration of mercury in hair is related to the concentration of methyl mercury in the blood at the time of hair synthesis, the analysis of hair can be used to monitor the past history of blood concentrations (Bakir et al. 1973, Al-Shahristani et al. 1974). The relations between observed hair and blood concentrations have been reported (Report from an Expert Group, 1971); the hair concentration was 140–400 times (mean approx. 300) that in blood.

External counting of men after ingestion of radioactive methyl mercury indicated the following tissue distribution (Falk et al. 1970):

Cerebellum	10%
Liver	54%
Remainder of body	36%

This distribution did not change greatly during two months after uptake but the proportion in brain rose slightly due to more rapid excretion from other organs. A similar distribution was found by Aberg et al. (1969). Experiments by Miettinen et al. (1971) showed that at 100 days after a single ingestion blood contained 5–10% of the methyl mercury in the whole body. In the blood about 5–20% (mean 10%) was found to be in plasma and the remaining 80–95% in the red cells (Bakir et al. 1973, Birke et al. 1972).

Measurements of the half-time of retention in the body and tissues of man yielded the following results:

Tissue	$T_{1/2}$ (days)	Reference
Body	71	Miettinen et al. (1971)
	72	Al-Shahristani and Shihab (1974)
	76	Falk et al. (1970)
Cerebellum	85	Falk et al. (1970)
Hair	100	Kojima and Fujita (1973) Miettinen et al. (1971)
Red blood cells, plasma	50	Miettinen et al. (1971)
Blood	50	Miettinen et al. (1971)
Liver	80	Kojima and Fujita (1973)
Kidney	56	Kojima and Fujita (1973)
Brain	41	Kojima and Fujita (1973)

Of the total methyl mercury excreted, the fraction in faeces is high and variable declining from about 0.95 in the first day or two after a single uptake to about 0.6 at 60 days (Aberg et al. 1969, Miettinen et al. 1971). In industrial workers chronically exposed to vapours of methyl mercury the measured concentrations in blood were from 6–50 times the concentration in urine (Lundgren et al. 1967).

(ii) Mammals and chickens

(a) Tissue distribution

	Relative concentrations						
Tissue	Mouse[a]	Rat[a,b,c]	Cat[b,d]	Dog[b]	Pig[b]	Monkey[b]	Chicken[e]
Brain	1	1	1	1	1	1	1
Blood	1	7–13	1	2	0.5	0.15	1
Kidney	1–10	5–40	2–4	2	3	1	2
Liver	4	3–4	7–24	4	5	1	2
Muscle			2				1

[a] Report from an Expert Group (1971)
[b] Kojima and Fujita (1973)
[c] Swensson and Ulfvarson (1968b)
[d] Hollins et al. (1975)
[e] Swensson and Ulfvarson (1968a)

(b) Retention equations

Rat

$$R_s(t) = 0.15e^{-(0.693/2)t} + 0.45e^{-(0.693/30)t} + 0.4e^{-(0.693/90)t} \qquad \text{(E4)}$$

Cat

$$R_s(t) = 0.1e^{-(0.693/0.8)t} + 0.9e^{-(0.693/T)t} \qquad \text{(E5)}$$

where

T = 117 days, including the hair
= 76 days, excluding the hair

Chicken

$$R_s(t) = e^{-(0.693/35)t} \tag{E6}$$

(iii) Wild birds

Hen pheasants with liver levels of 3–13 ppm laid eggs with 0.5–15 ppm and this
relating concentrations in food, feathers, blood, brain, and whole body are urgently

Swedish work over the past decade on the methyl mercury contents of wild birds' feathers has been summarized by Westermark et al. (1975). The methyl mercury content of feathers is a function of the concentration of methyl mercury in the blood at the time of feather formation. This is reflected in variation from feather to feather and even from one part of the feather to another. Since feathers have the highest concentrations of any tissue and since these concentrations reflect the food concentration, the analysis of birds' feathers provides good information about environmental contamination. Published data on tissue distributions in wild birds are scanty. Food, carcass, and liver have been analysed for great blue heron (Dustman et al. 1970) and common tern (Fimreite 1970). Brain, pectoral muscle, and feathers have been analysed in white-tailed eagles found dead in the Archipelago of Stockholm from 1965 to 1969 (Jensen et al. 1972). Systemic data relating concentrations in food, feathers, blood, brain, and whole body are urgently required for environmental assessment.

3. Fish

The respiratory uptake of methyl mercury through the gills of freshwater fish has been shown experimentally by de Freitas and Hart (1975) to be dependent on the metabolic rate and has been formulated, for 20°C, as:

$$\underset{\text{resp}}{I(t)} = 1000 \times m^{0.8} \times C_{pw} \text{ g methyl mercury/day} \tag{E7}$$

where

$\underset{\text{resp}}{I(t)}$ = rate of uptake by gills, g/day
m = body mass, g
C_{pw} = concentration of methyl mercury in water, g/g

The uptake of methyl mercury by the ingestion of contaminated food was shown to depend on the rates of maintenance metabolism and of growth (Norstrom et al. 1975). Thus, at 20°C,

$$\underset{\text{ing}}{I(t)} = C_{pf}\left(0.025m^{0.8} + 2\frac{dm}{dt}\right) \text{ g methyl mercury/day} \tag{E8}$$

where

$I(t)_{ing}$ = rate of uptake from the intestinal tract, g/day
C_{pf} = concentration of methyl mercury in food, g/g
m = body mass, g
$\frac{dm}{dt}$ = daily increase in body mass, g/day

By analyses of whole fish, 65–90% of the retained mercury was found to be in the form of methyl mercury (Burrows and Krenkel 1973, Lockhart et al. 1972); in fish muscle the proportion was uniformly >90%. Analysis of northern pike contaminated under natural conditions (Lockhart et al. 1972) and rainbow trout dosed in the laboratory (Giblin and Massaro 1973) showed that muscle concentration was representative of the concentration in the whole body and that no tissue concentrated methyl mercury more than by a factor of 2.

The half-time of retention has been variously estimated for adults of different species as follows:

Species	Body mass(g)	$T_{1/2}$(days)	Reference
Bluegills	2.5–11	640	Burrows and Krenkel (1973)
Pike	300 (mean)	640–780	Järvenpää et al. (1970)
Flounder	180 (mean)	640–780	Järvenpää et al. (1970)
Eel	100 (mean)	1030	Järvenpää et al. (1970)

In Canadian freshwater fish (7 species) ranging in weight from 1–400 g de Freitas et al. (1975) found that the biological half-life of methyl mercury was a function of body mass regardless of species. In their notation

$$R_{pcl} = k_{cl} \cdot P \cdot W^{-0.58} \qquad \text{(E9)}$$

where

R_{pcl} = the rate of elimination from the body (μg/day)
k_{cl} = the elimination constant for a fish weighing 1 g = 0.029
P = the body content of methyl mercury (μg)
W = the mass of the fish (g)

Thus $0.029 \cdot W^{-0.58}$ is the elimination constant (half-life = $24\ W^{+0.58}$ days) for a fish of body mass W g.

Giblin and Massaro (1973) found that in trout given a single dose of labelled methyl mercury by stomach tube half of the dose was deposited in muscle with a half-life >200 days. At 100 days after dosing 73% of the dose was retained in the whole animal. Their data suggest 80% with a long half-life, calculated to be 700 days from de Freitas' formula for 270 g fish. Their data for early loss, coupled with the above information suggest

$$R(t) = 0.1\mathrm{e}^{-(0.693/6)t} + 0.1\mathrm{e}^{-(0.693/200)t} + 0.8\mathrm{e}^{-(0.693/700)t}$$

In goldfish studied in the laboratory, de Freitas (Ottawa River Project 1976) found that increasing the uptake rate of methyl mercury from 0.05 to 0.35 micrograms per fish per day lowered the biological half-time by 50% (from 160 to 80 days).

Since water and food concentrations of methyl mercury are magnified in fish muscle by metabolic processes, the analysis of fish muscle for methyl mercury is a useful method of monitoring the hazard to man resulting from mercury contamination of the aquatic environment. If one knew the concentration of methyl mercury in water it would be a straightforward matter to calculate the concentration in fish muscle.

The body content in fish at t days after entry of methyl mercury into a river may be calculated from the equation (Butler 1972)

$$q(t) = \int_0^t I(\zeta)R_s(t-\zeta)\,d\zeta \quad \text{(See p. 213 for explanation)} \qquad \text{(E10)}$$

The rate of uptake of methyl mercury from water by the gills

$= 1000 \times m^{0.8} \times C_{pw}$, from equation (E7)

and since the uptake from food approximately equals the respiratory uptake the total uptake rate

$$I(\zeta) = 2000 \times m^{0.8} \times C_{pw}$$

$R_s(t-\zeta)$ = the fractional retention at $(t-\zeta)$ days after the uptake

$$= \mathrm{e}^{-0.029m^{-0.58}(t-\zeta)}, \text{ from equation (E9)} \qquad \text{(E11)}$$

$$\therefore q(t) = \int_0^t 2000 \times m^{0.8} \times C_{pw} \times \mathrm{e}^{-0.029m^{-0.58}(t-\zeta)}d\zeta \qquad \text{(E12)}$$

Unfortunately analytical techniques for analysing water for the very low levels of methyl mercury in natural waters, are not yet available. Failing this C_{pw} can be calculated from an observed rate of methyl mercury production and the volume of water into which it is released. For example, in the study of the Ottawa River, the velocity of flow was 17 km/d and 17 km had an area of sediment of 17×10^6 m². If this were all methyl mercury-producing sediment it would yield $2 \times 17 \times 10^6$ μg/day (Langley 1973). Since the volume of flow was 1.5×10^{11} l/day the resulting concentration would be 2.3×10^{-13} g/g. From equation (E7), for a 100 g fish, $I(t) = 9$ ng/day. If the uptake from ingestion approximately equals the uptake from respiration the total uptake is approximately 18 ng/day. $R_s(t)$ for a 100 g fish = $\mathrm{e}^{-0.002t}$ so at equilibrium

$$q(\infty) = \frac{18}{0.002} = 9000 \text{ ng}$$

and for a 100 g fish the concentration = 90 ng/g.

In the Ottawa River study the observed levels were twice as high as this calculated value which could have several explanations:

- the rate of methyl mercury production (2 micrograms/m^2/day) used in the calculation was not appropriate to this section of river;
- there was an appreciable content of methyl mercury in the water entering the study area;
- the fish were feeding on plants or animals that had already concentrated methyl mercury;
- the fish were adults and had in previous years been exposed to higher concentrations of methyl mercury.

For calculations like those above it would be desirable to have more precise knowledge of the rate of methyl mercury production as a function of the mercury content of sediments. Thus monitoring of the sedimental mercury coupled with data for the flow rate of the river would permit calculation of C_{pw} and from that the amount of methyl mercury in fish according to equation (E12).

4. Aquatic Plants (Mortimer and Kudo 1975)

Laboratory experiments showed that *Elodea* has an uptake rate of 7×10^{-9} g per day (of both inorganic and methyl mercury) per g (dry weight) of plant at a water concentration of 5×10^{-12} g/g. The corresponding figure for *Utricularia* was 22 ng/g/day. In a natural river *Elodea* gave an uptake rate of 15 ng/g/day at a concentration of 5×10^{-12} g/g, in good agreement with the laboratory values.

Measurements of the rate of loss from such plants showed that the rate was independent of the state of the plant (living or dead) and that the data were fitted by the retention equation

$$R_s(t) = 0.4e^{-(0.693/140)t} + 0.6e^{-(0.693/700)t} \qquad \text{(E13)}$$

Such a slow rate of loss from the plant tissue means that there will be an almost linear accumulation of methyl mercury during the life of the plant.

CRITICAL ORGANS AND TOXIC LEVELS

Symptoms of methyl mercury poisoning are seen to involve the central nervous system, and at lower levels possibly reproductive failure. As far as it is possible to tell, the symptoms seem to be the same in man, smaller mammals, and birds. One feature of methyl mercury poisoning is the latent period: the symptoms usually appear a few weeks or months after the first exposure to contaminated food.

In man pre-natal poisoning causes mental retardation and motor disturbances resembling cerebral palsy from other causes. Post-natal poisoning is characterized by sensory disturbances, ataxia and distortion of the visual field and hearing (Report from a Expert Group 1971).

In mice the earliest sign of poisoning, i.e., loss of the ability to hold the head in a horizontal position when the mouse is suspended by the tail, occurred at brain concentrations of 10 micrograms/g.

When rats ingested methyl mercury for 150–210 days and were examined for neurological (N) and morphological (M) lesions the following results were obtained:

Daily ingestion (mg/kg body weight)	Symptoms
1	N, M
0.5	M
0.2	0

In studies of the epidemics of methyl mercury poisoning among the fish-eating populations of Minamata and Niigata, the hair and blood of subjects showing symptoms were analysed at various times up to 1,000 days after the onset of symptoms. By extrapolating these plots back to zero time the concentrations corresponding to the appearance of symptoms could be obtained (Kojima and Fujita 1973, summarized by Skerfving 1972). In 17 cases at Niigata a blood concentration at zero time of 0.10 micrograms/g was the level below which there were no symptoms.

In the farmers of Iraq poisoned by eating bread made from methyl mercury-treated grain, it was reported (Dhahir and Clarkson 1974) that the toxic effects of methyl mercury became detectable when individuals had accumulated 0.5–0.8 mg mercury/kg body weight. This would correspond to a blood concentration in Standard Man of about 1 microgram/g. On the other hand, a plot of total neurological symptoms against blood concentration (Table 4 in Bakir et al. 1973) gave a linear relation passing through the origin. Reading off from this plot a blood level of 100 ng/ml corresponded to an incidence of 2% of minor neuromuscular disorders.

In 1969 an American family in the state of New Mexico was poisoned by eating pork from a pig fed on methyl mercury-contaminated grain (Pierce et al. 1972). In this episode it was estimated that each member of the family consumed 390 mg of methyl mercury during 100 days which, for the adults weighing 70 kg would be a daily intake of 55 micrograms/kg. Both parents remained unaffected but three children aged 8, 13, and 20 had severe neurological disorders; because of their smaller body weight their intakes would have been relatively higher. In the three children with neurological disorders the serum concentration of methyl mercury was 2–3 ppm and the hair concentration was 800 times higher.

OBJECTIVES AND STANDARDS

The following considerations and calculations show how standards for the protection of man might be derived. A blood concentration of 0.1 micrograms/g whole blood might be considered acceptable; this would correspond to 30 micrograms/g in hair (Skerfving 1972). If 10% of the methyl mercury is in the blood (Miettinen et al. 1971) this would correspond to a whole body content of

$$0.1 \times 5500 \times 10 \simeq 5 \text{ mg}$$

Assuming $T_{1/2} = 72$ days this equilibrium level would be attained by the daily uptake of 50 micrograms. For a 70 kg man this is 0.75 microgram/kg/day. By applying any safety factor deemed necessary to this number an acceptable daily intake (uptake) can be calculated.

1. Food

Since the main source of intake of methyl mercury for man is dietary fish, objectives or secondary standards are usually given in terms of the concentration of methyl mercury in fish (Skerfving 1972).

Japan	'Banning' of fish is considered when it contains more than 1 ppm (micrograms/g) or when the level in the hair of fish-eaters is >50 micrograms/g
Canada and USA	0.5 ppm in fish
Italy and Germany	0.5 ppm in fish
France	0.7 ppm in fish
Sweden	1.0 ppm in fish for consumption of fish once per week

In light of the above calculations these standards appear adequate to protect average populations, but they may need modification for groups with excessive consumption of contaminated fish.

2. Air

0.01 mg/m^3 in air (Report from an Expert Group 1971)

3. Drinking Water

0.0005 mg/kg (Report from an Expert Group 1971)

ENVIRONMENTAL SIGNS

a. Of Pollution

Mercury content of bottom sediments.
Methyl mercury content of fish muscle.
Methyl mercury content of birds' feathers.
Methyl mercury content of the hair of man and animals.
Methyl mercury content of underwater aquatic plants.

b. Of Effects

Rates of death and reproduction in seed- and fish-eating birds.
Health of domestic cats.

METHODS OF ANALYSIS AND LIMITS OF DETECTION
(total mercury analysis)
(Report from an Expert Group 1971)

Method	Limit(s) of detection
(a) Dithizone methods	0.5 micrograms/10 g dry sample
(b) Atomic absorption analysis	10 ng/g tenths of ng/0.2 g sample 2 ng/1 ml urine
(c) Neutron activation analysis	100–500 ng/g 0.1–0.2 ng/g in 1 g sample 0.02–0.03 ng/g in 10 ml sample
(d) Isotope dilution	0.04 ng/g
(e) Micrometric method	

(For methyl mercury analytical procedures, see Report from an Expert Group 1971.)

EQUATIONS

In this section are explained three of the mathematical formulations used; its purpose is to make the non-mathematical reader feel confident in the use of the formulae.

Equation (E1)

Assume that the concentration of total mercury in the food is C of which the fraction F is in the form of methyl mercury and $(1 - F)$ is in the form of inorganic mercury. If a fraction 0.95 of methyl mercury, and 0.15 of inorganic mercury, is absorbed from the intestinal tract to blood the total mass of mercury absorbed from 1 g of food is

$$0.95\,FC + 0.15(1 - F)\,C\ \mathrm{g}$$

Thus, of the total mercury absorbed into the body, the fraction in the form of methyl mercury

$$F_a = \frac{0.95FC}{0.95FC + 0.15(1 - F)C}$$

$$= \frac{0.95F}{0.95F + 0.15(1 - F)}$$

$$= \frac{0.95F}{0.95F + 0.15 - 0.15F}$$

$$\frac{0.95F}{0.8F + 0.15}$$

Dividing the numerator and denominator by F

$$F_a = \frac{0.95}{0.8 + \frac{0.15}{F}}$$

Equation (E3)

The retention function $R(t)$ is a function of time representing the fraction remaining in the body t days after uptake of a unit dose. If a continuous uniform dose rate is represented by I units per day that has continued for n days the amount remaining after n days will be

$$IR(n) + IR(n-1) + \ldots IR(1)$$

The first of these terms represents the amount remaining after n days from the uptake on the first day and so on, the last term representing the amount remaining from yesterday's uptake.

In continuous terms this sum is represented by

$$q(n) = \int_0^n IR(t)\,dt = I \int_0^n R(t)\,dt$$

where $q(n)$ = the total amount retained after n days of continuous uptake.

If the dose varies with time we can represent it as a function of time $I(t)$ and the fraction remaining after n days is $R(n-t)$ where $(n-t)$ is the number of days from the time of uptake t to the time of evaluation n.

Thus

$$q(n) = \int_0^n I(t)\,R(n-t)\,dt \quad \text{or} \quad \int_0^n I(n-t)\,R(t)\,dt$$

The two expressions are equivalent for this kind of integral which is called a convolution of I and R.

Equation (E2)

If we assume the $R(t)$ used above is described by a simple exponential decay, as is frequently the case.

$$R(t) = e^{-xt}$$

where

x is the fraction lost per day $= \frac{0.693}{T}$

T is the half-time of loss from the body, in days

For a constant intake as explained above,

$$q(n) = I \int_0^n R(t)\,dt$$

If n days is a much larger time than the half-time T, the amount lost from the body each day becomes equal to the amount taken up and the body content becomes constant at

$$q(\infty) = I \int_0^\infty e^{-xt}\,dt$$

$$= \frac{I}{x}$$

The grams of pollutant taken up by the predator each day,
where

$I = amfb$
a = g of prey eaten per g of predator
m = body mass of predator (g)
f = fraction of the pollutant in the prey absorbed from the intestines into the blood of the predator
b = concentration of pollutant in the prey (g/g)

$$\therefore a(\infty) = \frac{amf}{x} b$$

and the concentration of pollutant in the predator

$$\frac{q(\infty)}{m} = \frac{af}{x} b$$

Similarly, the predator of the first predator will have a body concentration of

$$\left[\frac{a_1 f_1}{x_1} \times \frac{a_2 f_2}{x_2}\right] b$$

and so on with one term for each step in the food chain.

If the equation describing retention in any level of the food chain is more complicated than a single exponential the algebra is slightly more complicated, e.g.,

If

$$R(t) = \alpha e^{-xt} + \beta e^{-yt} \qquad (\alpha + \beta = 1)$$

the magnification factor becomes

$$af\left[\frac{\alpha}{x} + \frac{\beta}{y}\right]$$

instead of

$$\frac{af}{x}.$$

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